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(54) **FILOVIRUS FUSION PROTEINS AND THEIR USES**

FILOVIRUS-FUSIONSPROTEINE UND IHRE VERWENDUNGEN

PROTÉINES DE FUSION DE FILOVIRUS ET LEURS UTILISATIONS

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- **PHOOLCHAROEN WARANYOO ET AL: "Transient Expression of Ebola Immune Complex in Nicotiana benthamiana", PLANT PHYSIOLOGY; PLANT BIOLOGY (ROCKVILLE) 2009 - JOINT ANNUAL MEETING OF THE AMERICAN-SOCIETY-OF-PLANT-BIOLOGISTS/ AMERI CAN SOCIETY OF PLANT PHYSIOLOGISTS , vol. 2009, no. Suppl. S 1 January 2009 (2009-01-01), page 310, XP008157412, ISSN: 0032-0889 Retrieved from the Internet: URL:http://abstracts.aspb.org/pb2009/public/P46/P46004.html [retrieved on 2012-10] & WARANYOO PHOOLCHAROEN ET AL: "Expression of an immunogenic Ebola immune complex in Nicotiana benthamiana", PLANT BIOTECHNOLOGY JOURNAL, vol. 9, no. 7, 1 September 2011 (2011-09-01), pages 807-816, XP008157354, WILEY-BLACKWELL PUBLISHING LTD, UNITED KINGDOM ISSN: 1467-7652, DOI: 10.1111/J.1467-7652.2011.00593.X [retrieved on 2011-02-01]**
- **KONDURU KRISHNAMURTHY ET AL: "Ebola virus glycoprotein Fc fusion protein confers protection against lethal challenge in vaccinated mice", VACCINE, vol. 29, no. 16, April 2011 (2011-04), pages 2968-2977, XP002685794,**
- **HASHIGUCHI TAKAO ET AL: "Structural basis for Marburg virus neutralization by a cross-reactive human antibody.", CELL 26 FEB 2015, vol. 160, no. 5, 26 February 2015 (2015-02-26), pages 904-912, ISSN: 1097-4172**

Remarks:

The file contains technical information submitted after the application was filed and not included in this specification

Description

FIELD OF THE INVENTION

[0001] This invention relates to the use of Filovirus glycoprotein fusion proteins for the prevention and diagnosis of Filovirus infection.

BACKGROUND OF THE INVENTION

[0002] Ebola virus (EBOV) and Marburgvirus (MARV) are members of the Filoviridae, a family of viruses classified as "Category A" bioterrorism agents that cause severe hemorrhagic fever in humans and nonhuman primates with high morbidity and mortality rates up to 90% (Sanchez et al., Filoviridae: Marburg and Ebola viruses, p. 1409-1448. In D. M. Knipe, P. M. Howley, D. E. Griffin, M. A. Martin, R. A. Lamb, B. Roizman, and S. E. Straus (ed.), Fields Virology, 5th ed. Philadelphia, PA.: Lippincott Williams & Wilkins" 2007). After a short incubation period of 4 to 10 days, Filovirus-infected individuals develop an abrupt onset of symptoms that include fever, chills, malaise, and myalgia that are common to many other viral infections. MARV is antigenically stable and exists in only one species, whereas EBOV is more variable and has five species. The Bundibugyo EBOV emerged recently in late 2007 outbreak in Uganda (Towner et al., PLoS Pathog 2008 Nov;4(11):e1000212), and is more related to the Ivory Coast than to the Zaire, Sudan, or Reston EBOV species. Zaire EBOV (ZEBOV) is typically associated with the highest lethality. The increased number of outbreaks in Africa and the recent EBOV outbreak in pigs (Normile Science 2009 Jan 23;323(5913):451), which raised concerns that livestock could transmit the deadly disease to humans, highlighted the urgency for the development of vaccines and rapid diagnostic tests to contain outbreaks. Vaccines based on the Filovirus glycoprotein (GP) are in preclinical and clinical evaluation, and currently there are no therapeutic agents to treat Filovirus infection Since licensing of safe and effective Filovirus vaccine could take several more years, diagnosis and quarantine of infected individuals is currently the main tool to limit outbreaks.

[0003] Several Filovirus vaccine candidates are currently being developed, including recombinant adenovirus expressing the EBOV GP (Sullivan et al., PLoS Med 2006 Jun;3(6):e177; Sullivan et al., Nature 2003 Aug 7;424(6949):681-4; and Sullivan et al., Nature 2000 Nov 30;408(6812):605-9), recombinant parainfluenza virus (Bukreyev et al., J Virol 2007 Jun;81(12):6379-88), recombinant Venezuelan equine encephalitis virus (Pushko et al., Vaccine 2000 Aug 15;19(1):142-53), recombinant replication-competent (Feldmann et al., PLoS Pathog 2007 Jan;3(1):e2 and Jones et al., Nat Med 2005 Jul;11(7):786-90) and-deficient (Halfmann et al., J Virol 2009 Apr;83(8):3810-5) vesicular stomatitis virus, and virus-like particles carrying the Filovirus GP (Warfield et al., Proc Natl Acad Sci USA 2003 Dec 23;100(26):15889-94 and Warfield et al., J Infect Dis 2007 Nov 15;196 Suppl2:S430-7). Initial studies using baculovirus-expressed Filovirus GP showed partial protection, which could be attributed to the nature of the glycosylation and processing of GP in insect cells(Mellquist-Riemenschneider et al., Virus Res 2003 Apr;92(2):187-93). Phoolchareon et al. (2009) discloses transient expression of Ebola Immune Complex in Nicotiana benthamiana (Joint Annual Meeting of the American Society of Plant Biologists/American Society of Plant Physiologists, vol. 2009, suppl., page 310). WO2006/046963 discloses generation of virus-like particles and their use as filovirus vaccine. US2003/0224015 discloses Ebola peptides and related immunogenic compositions. WO01/07081 discloses Fc fusion proteins for enhancing the immunogenicity of protein and peptide antigens.

[0004] Despite advances in this regard, a need exists to develop new vaccines against Filovirus infections. The present invention addresses these and other needs.

BRIEF SUMMARY OF THE INVENTION

[0005] The present invention provides a fusion protein comprising a Filovirus glycoprotein segment comprising the extracellular domain and an immunoglobulin polypeptide segment comprising an Fc fragment of an immunoglobulin heavy chain constant domain polypeptide, wherein the C-terminus of the Filovirus glycoprotein segment is attached to the N-terminus of the immunoglobulin polypeptide segment. In the typical embodiment, the Filovirus glycoprotein extracellular domain is, for example, from an Ebola virus, particularly, the Zaire Ebola virus, Mayinga strain. The immunoglobulin polypeptide segment can be from IgG1. In some embodiments, the fusion protein may further comprise a linker between the Filovirus glycoprotein segment and the immunoglobulin polypeptide segment. An exemplary fusion protein of the invention is encoded by a nucleic acid sequence as shown in SEQ ID NO:1 without a linker and SEQ ID NO:3 with a FLAG tag linker.

[0006] The invention further provides immunogenic compositions comprising the fusion protein of the invention. The immunogenic composition may further comprise an adjuvant.

[0007] Also provided are nucleic acid vectors comprising a nucleic acid sequence encoding a fusion protein of the invention. An exemplary nucleic acid sequence is shown in SEQ ID NO: 1.

[0008] The invention provides the immunogenic compositions of the invention for use in a method of inducing a protective immune response against Filovirus infection in a patient. The methods comprise administering to the patient an immunologically effective amount of the immunogenic composition of the invention. The immunogenic composition can comprise the fusion proteins of the invention or nucleic acid molecules encoding them. The composition can be administered by any of a number of routes. In some embodiments, the composition is administered intramuscularly.

[0009] The invention also provides methods of detecting an immune response against Filovirus in a patient, the methods comprising contacting a biological sample from the patient with the fusion protein of the invention and detecting an immune response, for example, either a humoral or a cellular immune response. Antibodies can be detected using ELISA, chemiluminescence assays, or fluorescence assays. A cellular immune response can be detected by detecting IFN-γ, TNF-α, or other cytokines and cell activation and proliferation assays.

[0010] Yet another aspect of the disclosure are methods of detecting anti-Filovirus antibodies (*e.g.,* neutralizing antibodies) in a biological sample from a patient immunized with Filovirus glycoprotein Fc fusion proteins or other immunogens. Such methods comprise contacting the biological sample with a recombinant Vesicular Stomatitis Virus (VSV) expressing a Filovirus GP (*e.g.,* a Zaire Ebola virus, Mayinga strain) and assessing residual infectivity in a cell susceptible to Filovirus infection. The cells used in the assay can be Vero E6 cells. Alternatively the recombinant VSV particles can be immobilized on a solid support and anti-Filovirus antibodies can be detected using standard methods, such as ELISA, chemiluminescence assays, or fluorescence assays.

DEFINITIONS

[0011] The terms "adjuvant" and "immune stimulant" are used interchangeably herein, and are defined as one or more substances that cause stimulation of the immune system. In this context, an adjuvant is used to enhance an immune response to the fusion proteins of the invention.

[0012] The terms "amino-terminal" (or "N-terminal") and "carboxyl-terminal" (or "C-terminal") are used herein to denote positions within polypeptides, particularly fusion proteins of the invention. Where the context allows, these terms are used with reference to a particular sequence or segment of a polypeptide or protein to denote proximity or relative position. For example, a certain sequence positioned carboxyl-terminal to a reference sequence within a polypeptide is located proximal to the carboxyl terminus of the reference sequence, but is not necessarily at the carboxyl terminus of the complete polypeptide.

[0013] The term "corresponding to", when applied to positions of amino acid residues in sequences, means corresponding positions in a plurality of sequences when the sequences are optimally aligned.

[0014] The term "expression vector" refers to a linear or circular DNA molecule that comprises a segment encoding a polypeptide of interest (*e.g.,* a fusion protein of the invention) operably linked to additional segments that provide for its transcription. Such additional segments include promoter and terminator sequences, and may also include one or more origins of replication, one or more selectable markers, an enhancer, a polyadenylation signal, and the like. Expression vectors are generally derived from bacterial or viral DNA, and may contain elements of both.

[0015] The terms "identical" or percent "identity," in the context of two or more nucleic acids or polypeptide sequences, (*e.g.,* fusion proteins of the invention and polynucleotides that encode them) refer to two or more sequences or subsequences that are the same or have a specified percentage of amino acid residues or nucleotides that are the same, when compared and aligned for maximum correspondence, as measured using one of the following sequence comparison algorithms or by visual inspection.

[0016] The phrase "substantially identical," in the context of two nucleic acids or polypeptides of the invention, refers to two or more sequences or subsequences that have at least 60%, more preferably 65%, even more preferably 70%, still more preferably 75%, even more preferably 80%, and most preferably 90-95% nucleotide or amino acid residue identity, when compared and aligned for maximum correspondence, as measured using one of the following sequence comparison algorithms or by visual inspection. Preferably, the substantial identity exists over a region of the sequences that is at least about 50 residues in length, more preferably over a region of at least about 100 residues, and most preferably the sequences are substantially identical over at least about 150 residues. In a most preferred embodiment, the sequences are substantially identical over the entire length of the coding regions.

[0017] For sequence comparison, typically one sequence acts as a reference sequence, to which test sequences are compared. When using a sequence comparison algorithm, test and reference sequences are input into a computer, subsequence coordinates are designated, if necessary, and sequence algorithm program parameters are designated. The sequence comparison algorithm then calculates the percent sequence identity for the test sequence(s) relative to the reference sequence, based on the designated program parameters.

[0018] Optimal alignment of sequences for comparison can be conducted, *e.g.,* by the local homology algorithm of Smith & Waterman, Adv. Appl. Math. 2:482 (1981), by the homology alignment algorithm of Needleman & Wunsch, J. Mol. Biol. 48:443 (1970), by the search for similarity method of Pearson & Lipman, Proc. Nat'l. Acad. Sci. USA 85:2444 (1988), by computerized implementations of these algorithms (GAP, BESTFIT, FASTA, and TFASTA in the Wisconsin

Genetics Software Package, Genetics Computer Group, 575 Science Dr., Madison, WI), or by visual inspection (*see generally,* Current Protocols in Molecular Biology, F.M. Ausubel et al., eds., Current Protocols, a joint venture between Greene Publishing Associates, Inc. and John Wiley & Sons, Inc., (1995 Supplement) (Ausubel)).

[0019] Examples of algorithms that are suitable for determining percent sequence identity and sequence similarity are the BLAST and BLAST 2.0 algorithms, which are described in Altschul et al. (1990) J. Mol. Biol. 215: 403-410 and Altschuel et al. (1977) Nucleic Acids Res. 25: 3389-3402, respectively. Software for performing BLAST analyses is publicly available through the National Center for Biotechnology Information (http://www.ncbi.nlm.nih.gov/). This algorithm involves first identifying high scoring sequence pairs (HSPs) by identifying short words of length W in the query sequence, which either match or satisfy some positive-valued threshold score T when aligned with a word of the same length in a database sequence. T is referred to as the neighborhood word score threshold (Altschul *et al, supra*). These initial neighborhood word hits act as seeds for initiating searches to find longer HSPs containing them. The word hits are then extended in both directions along each sequence for as far as the cumulative alignment score can be increased. Cumulative scores are calculated using, for nucleotide sequences, the parameters M (reward score for a pair of matching residues; always > 0) and N (penalty score for mismatching residues; always < 0). For amino acid sequences, a scoring matrix is used to calculate the cumulative score. Extension of the word hits in each direction are halted when: the cumulative alignment score falls off by the quantity X from its maximum achieved value; the cumulative score goes to zero or below, due to the accumulation of one or more negative-scoring residue alignments; or the end of either sequence is reached. The BLAST algorithm parameters W, T, and X determine the sensitivity and speed of the alignment. The BLASTN program (for nucleotide sequences) uses as defaults a wordlength (W) of 11, an expectation (E) of 10, M=5, N=-4, and a comparison of both strands. For amino acid sequences, the BLASTP program uses as defaults a wordlength (W) of 3, an expectation (E) of 10, and the BLOSUM62 scoring matrix (*see* Henikoff & Henikoff, Proc. Natl. Acad. Sci. USA 89:10915 (1989)).

[0020] In addition to calculating percent sequence identity, the BLAST algorithm also performs a statistical analysis of the similarity between two sequences (*see, e.g.,* Karlin & Altschul, Proc. Nat'l. Acad. Sci. USA 90:5873-5787 (1993)). One measure of similarity provided by the BLAST algorithm is the smallest sum probability (P(N)), which provides an indication of the probability by which a match between two nucleotide or amino acid sequences would occur by chance. For example, a nucleic acid is considered similar to a reference sequence if the smallest sum probability in a comparison of the test nucleic acid to the reference nucleic acid is less than about 0.1, more preferably less than about 0.01, and most preferably less than about 0.001.

[0021] A further indication that two nucleic acid sequences or polypeptides of the invention are substantially identical is that the polypeptide encoded by the first nucleic acid is immunologically cross reactive with the polypeptide encoded by the second nucleic acid, as described below. Thus, a polypeptide is typically substantially identical to a second polypeptide, for example, where the two peptides differ only by conservative substitutions. Another indication that two nucleic acid sequences are substantially identical is that the two molecules hybridize to each other under stringent conditions, as described below.

[0022] An "immunoglobulin" is a serum protein which functions as an antibody in vertebrate organisms. Each immunoglobulin comprises a light chain and a heavy chain. Each chain comprises a constant domain and a variable domain. There are five types of heavy chain, denoted by α, δ, ε, γ, and μ, which defines the class of antibody, IgA, IgD, IgE, IgG, and IgM, respectively. In humans, IgG consists of four subclasses, designated IgG1, IgG2, IgG3, and IgG4. DNA sequences encoding human and non-human immunoglobulin chains are well known in the art.

[0023] The term "immunoglobulin heavy chain constant domain polypeptide" denotes a wild-type immunoglobulin heavy chain constant domain or a variant thereof. An IgG constant domain comprises the C_H1, C_H2, and C_H3 domains and the hinge region.

[0024] An "Fc fragment" is a fragment of the heavy chain constant domain corresponding to the region of the immunoglobulin that interacts with Fc receptors. In IgG, IgA and IgD, the Fc region corresponds to C_H2, and C_H3 domains and the hinge region. In IgM and IgE, the Fc regions contain three heavy chain constant domains (C_H2, C_H3, and C_H4).

[0025] "Operably linked" indicates that two or more DNA segments are joined together such that they function in concert for their intended purposes. For example, coding sequences are operably linked to promoter in the correct reading frame such that transcription initiates in the promoter and proceeds through the coding segment(s) to the terminator.

[0026] A "polynucleotide" is a single- or double-stranded polymer of deoxyribonucleotide or ribonucleotide bases typically read from the 5' to the 3' end. Polynucleotides include RNA and DNA, and may be isolated from natural sources, synthesized in vitro, or prepared from a combination of natural and synthetic molecules. When the term is applied to double-stranded molecules it is used to denote overall length and will be understood to be equivalent to the term "base pairs".

[0027] A "polypeptide" is a polymer of amino acid residues joined by peptide bonds, whether produced naturally or synthetically. Polypeptides of less than about 50 amino acid residues are commonly referred to as "oligopeptides".

[0028] The term "promoter" is used herein for its art-recognized meaning to denote a portion of a gene containing

DNA sequences that provide for the binding of RNA polymerase and initiation of transcription of an operably linked coding sequence. Promoter sequences are typically found in the 5' non-coding regions of genes.

[0029] A "protein" is a macromolecule comprising one or more polypeptide chains. A protein may also comprise non-peptidic components, such as carbohydrate groups. Carbohydrates and other non-peptidic substituents may be added to a protein by the cell in which the protein is produced, and will vary with the type of cell. Proteins are defined herein in terms of their amino acid backbone structures; substituents such as carbohydrate groups are generally not specified, but may be present nonetheless.

[0030] The term "substantially similar" in the context of the fusion proteins of the invention indicates that a polypeptide comprises a sequence with at least 90%, preferably at least 95% sequence identity to the reference sequence (*e.g.,* the GP-Fc fusion exemplified here) over a comparison window of 10-20 amino acids. Percentage of sequence identity is determined by comparing two optimally aligned sequences over a comparison window, wherein the portion of the polynucleotide sequence in the comparison window may comprise additions or deletions (*i.e.,* gaps) as compared to the reference sequence (which does not comprise additions or deletions) for optimal alignment of the two sequences. The percentage is calculated by determining the number of positions at which the identical nucleic acid base or amino acid residue occurs in both sequences to yield the number of matched positions, dividing the number of matched positions by the total number of positions in the window of comparison and multiplying the result by 100 to yield the percentage of sequence identity.

BRIEF DESCRIPTION OF THE DRAWINGS

[0031]

Figure 1 is a schematic representation and purification of the ZEBOVGP-Fc and FLAG-Fc proteins. A) Schematic representation of the fusion proteins. The ZEBOVGP-Fc fusion protein contains the ectodomain of ZEBOV GP tagged at its C terminus with a FLAG peptide and fused to the hinge and Fc regions of human IgG1. The FLAG-Fc fusion protein contains a FLAG tag fused to the hinge and Fc regions of IgG1. B) SDS-PAGE analysis of fusion proteins. Protein A-purified ZEBOVGP-Fc and FLAG-Fc preparations were analyzed by denaturing SDS-PAGE in a 4-12% gradient gel and stained with Coomassie blue. C) Western blot analysis of ZEBOVGP-Fc and FLAG-Fc. Proteins were resolved by SDS-PAGE under denaturing conditions, transferred to PVDF membranes, and probed with ZEBOV-specific anti-GP1 mAb 13F6-1-2, anti-Flag M2 mAb, or goat anti-human Fc Ab. ZEBOV GP1, GP2-FLAG-Fc, and FLAG-Fc bands are indicated with arrows. Positions and size of molecular weight markers are indicated in kDa.

Figure 2 is a characterization of ZEBOVGP-Fc fusion protein. A) FPLC analysis of protein A-purified ZEBOVGP-Fc. Undigested (gray) or enterokinase-digested (blue) ZEBOVGP-Fc was run on a Superdex 200 size exclusion column under non-denaturing conditions, and absorbance at 280 nm was recorded for each of the 38 collected fractions. Peaks representing ZEBOVGP-Fc, ZEBOV GP, and Fc are marked with arrows. A peak of approximately 150 kDa represents a carrier protein in the enterokinase preparation. The migration of molecular weight standards is shown as arrowheads and their molecular weight is expressed in kDa. B) Western blot analysis of enterokinase-digested ZEBOVGP-Fc protein. Gel filtration peak fractions (20 and 32) were fractionated in denaturing SDS-PAGE, transferred to a PVDF membrane, probed with ZEBOV-specific anti-GP1 mAb 13F6-1-2 or goat anti-human anti-Fc antibody. Undigested (U) or enterokinase digested (D) ZEBOVGP-Fc, and FLAG-Fc (Fc) were included in the gel as markers. Arrows indicate the migration of GP1, GP2-FLAG-Fc, and FLAG-Fc. The migration of the molecular weight markers and their sizes are indicated in kDa.

Figure 3 shows analysis of anti-ZEBOV GP antibodies in vaccinated C57BL/6 mice. A) Analysis of anti-ZEBOV GP specific antibodies by viral particle ELISA. Mice were vaccinated with ZEBOVGP-Fc or FLAG-Fc and sera samples were obtained 2 weeks after the final vaccination. Sera were titrated on 96-well plates coated with sucrose-purified irradiated ZEBOV particles, rVSV-ZEBOVGP, or control wt VSV. The endpoint dilution titer for each mouse sera is represented as a dot. B) FACS analysis of binding of mouse sera to ZEBOV GP expressed at the cell surface of HEK293-ZEBOVGP cells. HEK293-ZEBOVGP or control vector-transfected HEK293 cells were stained with mouse sera (1 μl) and PE-conjugated goat anti-mouse IgG Ab and analyzed by flow cytometry. The histogram of each mouse sera is shown in a different color, and the histogram of the positive control anti-GP mAb 13F6-1-2 is shown as a dashed grey line. To simplify the graph, the same color was used for sera from two different mice, one vaccinated with ZEBOVGP-Fc (left panels) and the other with FLAG-Fc (right panels).

Figure 4 shows neutralization of rVSV-ZEBOVGP with sera from vaccinated C57BL/6 mice. A plaque reduction assay was performed in Vero E6 cells using 100 pfu of rVSV-ZEBOVGP treated with five-fold dilutions of sera from

mice vaccinated with ZEBOVGP-Fc or FLAG-Fc. Percent neutralization of each mouse serum was calculated as the reduction in the number of plaques compared to untreated rVSV-ZEBOVGP. The data show the mean percent neutralization in duplicate samples for each mouse sera dilution, and bars represent the standard deviations.

Figure 5 shows humoral immune response in BALB/c mice vaccinated with ZEBOVGP-Fc. Four BALB/c mice were immunized with ZEBOVGP-Fc or FLAG-Fc. Sera samples were collected 2 weeks after the final vaccination. A) Analysis of anti-ZEBOV GP-specific antibodies by viral particle ELISA on plates coated with rVSV-ZEBOVGP was done as described in Fig. 3A. B) Neutralization of rVSV-ZEBOVGP with sera from BALB/c mice vaccinated with ZEBOVGP-Fc or FLAG-Fc. Mean neutralization with 1/10 dilution sera was determined by a plaque reduction assay using duplicate samples as described in Fig. 4. The data show the mean (n=4) of the percent mean neutralization of each sample, and bars represent the standard deviation. The difference between neutralization of sera from ZEBOVGP-Fc- and FLAG-Fc-vaccinated mice is statistically significant (**, $p \leq 0.01$).

Figure 6 shows cellular immune response in BALB/c mice vaccinated with ZEBOVGP-Fc. Splenocytes from vaccinated BALB/c mice in Fig. 5 were collected eight days after the final immunization, stimulated with fusion proteins or peptides, and stained at the cell surface with APC-labeled anti-CD8 mAb and intracellularly with PE-labeled anti-IFN-γ mAb. The percent of IFN-γ- producing $CD8^+$ T-cells was determined by flow cytometry gating on $CD8^+$ splenocytes. A) Dot plot analysis of $CD8^+$ splenocytes from a representative mouse vaccinated with ZEBOVGP-Fc or FLAG-Fc and stimulated with ZEBOVGP-Fc or FLAG-Fc. Double-positive splenocytes expressing CD8 and IFN-γ are shown within a rectangular box and numbers represent the percentage of IFN-γ-positive $CD8^+$ cells within the box. B-E) Bar graph representation of the percentage of IFN-γ-positive $CD8^+$ cells in splenocytes from mice vaccinated with ZEBOVGP-Fc (B,D) or FLAG-Fc (C,E) and stimulated with Fc fusion proteins (B,C) or syntheic peptides (D,E). Splenocytes were stimulated with Fc fusion proteins ZEBOVGP-Fc or FLAG-Fc, or ZEBOV GP-specific or control synthetic peptides. The data represent the mean percentage of total CD8+ cells that express IFN-γ (n=4 mice), and the bars represent the standard deviations. The difference between the percentage of IFN-γ-positive $CD8^+$ splenocytes in ZEBOVGP-Fc-vaccinated mice stimulated with ZEBOVGP-Fc and FLAG-Fc is statistically significant (*, p=0.01).

Figure 7 shows that ZEBOVGP-Fc protected mice against a ZEBOV lethal challenge. Mice were vaccinated with ZEBOVGP-Fc (filled triangle) or FLAG-Fc (open squares) and challenged with 1,000 pfu of mouse adapted ZEBOV two weeks after the last vaccination. Results are plotted as percent survival for each vaccination group (n = 8 mice per group).

Figure 8 shows the results of experiments of virus particle ELISA of sera from guinea pigs vaccinated with with ZEBOVGP-Fc fusion protein. Seven guinea pigs (GP-Fc 1 to GP-Fc7) were vaccinated with ZEBOVGP-Fc in QS-21 adjuvant. Animals were bled after 2 boosts and sera was analyzed by virus particle ELISA for anti-ZEBOVGP antibodies. All animals develop high titers of anti-ZEBOVGP antibodies.

Figure 9 shows the results of experiments of virus particle ELISA of sera from guinea pigs vaccinated with with control Fc fragment. Seven guinea pigs (Fc 1 to Fc7) were vaccinated with Fc fragment alone in QS-21 adjuvant. Animals were bled after 2 boosts and sera was analyzed by virus particle ELISA for anti-ZEBOVGP antibodies. None of the animals develop anti-ZEBOVGP antibodies.

Figure 10 shows neutralization of Zaire Ebola virus pseudotype with sera from ZEBOVGP-Fc vaccinated guinea pigs. Zaire Ebola virus pseudotypes were neutralized with sera from guinea pigs vaccinated with ZEBOVGP-Fc or Fc fragment alone. Percent neutralization was determined in comparison to neutralization with pre-immune sera. All ZEBOVGP-Fc vaccinated animals developed anti-ZEBOV neutralizing antibodies whereas none of the Fc vaccinated animals developed anti-ZEBOV neutralizing antibodies.

Figure 11 shows analysis of anti-Ebola virus antibodies in three Rhesus monkeys. Prior to vaccination, sera from three monkeys was tested for anti-Ebola virus GP antibodies by virus particle ELISA. None of the monkeys had anti-Ebola virus antibodies.

Figure 12 shows that Rhesus monkeys vaccinated with ZEBOVGP-Fc developed anti-Ebola virus antibodies. Sera from 2 monkeys vaccinated with ZEBOVGP-Fc (GP-Fc1 and GP-Fc2) contained high titers of anti-Ebola virus antibodies as assessed by virus particle ELISA whereas sera from the control monkey vaccinated with Fc fragment alone (Fc) did not develop anti-Ebola virus antibodies.

Figure 13 shows neutralization of Ebola virus pseudotypes with sera from Rhesus monkeys vaccinated with ZEBOVGP-Fc. Sera from Rhesus monkeys GP-Fc1 and -2 that were vaccinated with ZEBOVGP-Fc and control monkey Fc vaccinated with Fc fragment alone was tested for anti-Ebola virus neutralization antibodies by an endpoint dilution assay in 96-well plates containing Vero E6 cell monolayers. Sera was collected 3 weeks after the primary immunization (Vaccine), animals were boosted with the corresponding vaccines and sera was collected 3 weeks after the boost (1st boost). Percent neutralization was determined in comparison to neutralization with pre-immune sera. The ZEBOVGP-Fc inoculated monkeys developed anti-Ebola virus neutralizing antibodies whereas the monkey inoculated with Fc control did not develop neutralizing antibodies.

DETAILED DESCRIPTION

[0032] The present invention demonstrates that fusion proteins comprising Filovirus glycoprotein (GP) segment fused to a immunoglobulin polypeptide segment undergo the cleavage and processing observed in native GP. The results presented here clearly indicate that the GP fusion proteins themselves without the need of a viral vector or the assembly into virus-like particles are sufficient for inducing protection against Filovirus infection and are useful as a safe and effective subunit vaccine against Filovirus infection.

[0033] As shown in detail below, the extracellular domain of a Filovirus GP (*e.g.,* ZEBOV GP) fused to an immunoglobulin segement (*e.g.,* Fc fragment of human IgG1) expressed in mammalian cells undergoes the complex posttranslational modification including the furin cleavage and homotrimer formation observed in the native GP. Vaccination with the Filovirus GP-IgG fusion protected mice against challenge with a lethal dose of Zaire EBOV. The results presented here demonstrate that the Filovirus GP-IgG fusions, without the need of a viral vector or the assembly into virus-like particles, are sufficient for inducing protection against Filovirus infection and demonstrate that Filovirus GP IgG fusion proteins are useful as cost-effective safe and effective subunit vaccine against Filovirus infection.

FILOVIRUS GP-IMMUNOGLOBULIN FUSION PROTEINS

[0034] Ebola viruses and Marburg viruses make up the family Filoviridae. There are five species of Ebola viruses, Zaire (type species), Sudan, Reston, Bundibugyo, and Ivory Coast. There is a single species of Marburg virus. The glycoprotein (GP) is the sole structural protein making up the virion surface spikes that mediate virus entry into susceptible host cells through receptor binding. GP is the most studied of the filovirus proteins, not only for its importance in virus entry and pathogenesis but because it is a prime target for vaccine development.

[0035] Filovirus particles contain a negative-strand RNA genome of about 19 kb long that encodes seven structural and one nonstructural protein (Volchkov et al., Adv Virus Res 2005;64:359-81). The envelop glycoprotein (GP) is present as spikes on the virion surface and is responsible for receptor binding, viral entry, and immunity (Feldmann et al., J Gen Virol 2001 Dec;82(Pt 12):2839-48 and Takada et al., Proc Natl Acad Sci USA 1997 Dec 23;94(26):14764-9). The Filovirus GP is a class 1 integral membrane glycoprotein derived from gene 4 that undergoes a complex processing involving furin cleavage and disulfide-bond formation between the N-terminus and the membrane proximal portion of the GP. The mature transmembrane GP present on the viral envelope and membrane of infected cells is formed by two subunits: the membrane anchored GP2 that is covalently linked via disulphide linkage to the N-terminus of GP1, which contains a highly o-glycosylated mucin-like domain (Volchkov et al., Proc Natl Acad Sci USA 1998 May 12;95(10):5762-7) and Jeffers et al., J Virol 2002 Dec;76(24):12463-72). A significant amount of GP1 is shed from the cells after release from the GP2 subunit. In addition, a nonstructural soluble glycoprotein (sGP) that shares the amino-terminal 295 amino acids with GP1, lacks a transmembrane anchor, and forms disulphide-linked homodimers, is produced by EBOV but not MARV infected cells (Feldmann et al., Curr Top Microbiol Immunol 1999;235:1-21).

[0036] A number of genes encoding Filovirus GP have been cloned and are described in the literature (*see e.g.,* WO 2006/037038). One of skill can readily clone a desired gene or use genes that have been previously described. Table 1 provides a summary of GenBank Accessions for exemplary GP sequences from various Ebola and Marburg virus subtypes.

Table 1

Virus	Subtype	Genbank Accession No.
Ebola	Ivory Coast	U28006
	Reston	U23152, NC_004161, AF034645, U23416, AY769362, AF522874, U23417
	Sudan	U28134, U23069, Q66798, AY729654, AY344234, AY316199
	Zaire	AY142960, AF499101, AF272001, AF086833, U23187, NC_002549, AY354458, U28077, U31033, P87666, U81161, AY058898, U77384, AY526105, AY526104, AY526103, AY526102, AY526101, AY526100, AY526099, AY526098
	Bundibugyo	ACI28624, FJ217161
Marburg		Z12132, AF005735, NC_001608, Z29337, X68493, AY358025, AF005733, AF005734, AY430365, AY430366

[0037] In the fusion proteins of the present invention, the GP protein can be full-length protein or fragment thereof comprising the GP extracellular domain. The extracellular domain may derived from a variety of sources. For example, it may be derived from a naturally occurring Filovirus glycoprotein, a mutated Filovirus glycoprotein (*e.g.,* a protein comprising a single point mutation, deletion of one or more amino acids, deletion of one or more domains such as mucin domain), or a chimeric Filovirus GP protein comprising domains of different strains, species, or genera of Filoviruses. As noted above, the GP protein of Ebola virus is well characterized and one of skill can easily identify the appropriate domain in the GP protein of a particular isolate. For example, in the exemplified GP described below, a fragment comprising the extracellular domain (residues 1-637 of the polypeptide sequence shown in GenBank accession no. U23187) was used. Using well-known sequence alignment techniques, one of skill could readily identify the corresponding fragment in GPs from other isolates.

[0038] The immunoglobulin segment of the fusion proteins of the invention can be derived from any class of antibody: IgA, IgD, IgE, IgG, or IgM. In the typical embodiment, human IgG polypeptides are used. As noted above, IgG molecules are categorized into four subclasses, designated IgG1, IgG2, IgG3, and IgG4. DNA sequences encoding human and non-human immunoglobulin chains are well known in the art.

[0039] In the usual embodiment, an immunoglobulin heavy chain constant region is used. As noted above, in the case of IgG molecules, the heavy chain constant region comprises the C_H1, C_H2, and C_H3 domains and the hinge region. In some embodiments, an Fc fragment is used. As noted above, in IgG, IgA and IgD, the Fc region corresponds to C_H2, and C_H3 domains and the hinge region. In IgM and IgE, the Fc regions contain three heavy chain constant domains (C_H2, C_H3, and C_H4). The hinge can serve as a flexible spacer between the two parts of the fusion protein, allowing each part of the molecule to function independently.

[0040] The preparation of fusion proteins comprising immunoglobulin heavy chain constant regions is well known. Many examples of such fusions are described in the literature (see, *e.g.,* U.S. Patent Nos. 7,754,855; 5,480,981; 5,723,125, 5,808,029; WO97/23614; WO98/28427 and references cited therein). Fc fusion proteins can include variant Fc molecules (*e.g.,* as described in U.S. Patent No. 7,732,570).

[0041] The Filovirus GP segment and immunoglobulin segment can be linked to each other in a variety of ways known to those of skill in the art. In the fusion protein of the invention, a Filovirus GP segment is fused to the immunoglobulin segment, wherein the C-terminus of the Filovirus GP segment is attached to the N-terminus of the immunoglobulin segment.

[0042] In some embodiments, the fusion protein can further comprise a peptide linker between the two segments. For example, the C-terminus of the Filovirus GP can be linked to the N-terminus of the immunoglobulin segment by a peptide linker. In general, the peptide linker is immunologically inert and is designed to allow proper processing of the Filovirus GP. The peptide linker may comprise, for example, a protease cleavage site or sequences to facilitate isolation of the fusion, such as epitope tags. Design and use of linker peptides is well known in the art.

[0043] Also included in the invention are nucleic acid molecules that encode the fusion proteins of the invention. The nucleic acid molecules of the invention may be in the form of RNA or in the form of DNA obtained by cloning or produced synthetically. The DNA may be double-stranded or single-stranded. By "isolated" nucleic acid molecule(s) is intended a nucleic acid molecule, DNA or RNA, which has been removed from its native environment. For example, recombinant DNA molecules contained in a vector are considered isolated for the purposes of the present invention. Further examples of isolated DNA molecules include recombinant DNA molecules maintained in heterologous host cells or purified (partially or substantially) DNA molecules in solution. Isolated RNA molecules include in vivo or in vitro RNA transcripts of the DNA molecules of the present invention. Isolated nucleic acid molecules according to the present invention further include such molecules produced synthetically.

[0044] Nucleic acid molecules of the present invention include DNA molecules comprising an open reading frame (ORF) encoding a fusion protein of the invention and DNA molecules which comprise a sequence substantially identical to those exemplified here but which, due to the degeneracy of the genetic code, still encode a fusion protein of the invention. Thus, in the typical embodiment, the nucleic acid molecules are expression vectors used to express the fusion proteins of the invention. A nucleic acid molecule encoding the polypeptide can be operably linked to regulatory sequences that control transcriptional expression in an expression vector and then, introduced into a host cell. In addition to transcriptional regulatory sequences, such as promoters and enhancers, expression vectors can include translational regulatory sequences and a marker gene which is suitable for selection of cells that carry the expression vector.

[0045] The fusion proteins polypeptides of the present invention can be produced in recombinant host cells following conventional techniques. The fusion proteins of the invention can be expressed in a wide variety of host cells, well known to those of skill in the art. For example, the proteins may be expressed in mammalian cells. Examples of suitable mammalian host cells include African green monkey kidney cells (*e.g.,* Vero; ATCC CRL 1587), human embryonic kidney cells (*e.g.,* 293-HEK; ATCC CRL 1573), baby hamster kidney cells (*e.g.,* BHK-21, BHK-570; ATCC CRL 8544, ATCC CRL 10314), canine kidney cells (*e.g.,* MDCK; ATCC CCL 34), Chinese hamster ovary cells (*e.g.,* CHO-K1; ATCC CCL61; CHO DG44), rat pituitary cells (*e.g.,* GH1; ATCC CCL82), HeLa S3 cells (*e.g.,* ATCC CCL2.2), rat hepatoma cells (*e.g.,* H-4-II-E; ATCC CRL 1548) SV40-transformed monkey kidney cells (*e.g.,* COS-1; ATCC CRL 1650) and murine embryonic cells (*e.g.,* NIH-3T3; ATCC CRL 1658).

[0046] For a mammalian host, the transcriptional and translational regulatory signals may be derived from mammalian viral sources, for example, adenovirus, bovine papilloma virus, simian virus, or the like, in which the regulatory signals are associated with a particular gene which has a high level of expression. Suitable transcriptional and translational regulatory sequences also can be obtained from mammalian genes, for example, actin, collagen, myosin, and metallothionein genes.

[0047] An expression vector can be introduced into mammalian host cells using a variety of standard techniques including calcium phosphate transfection, liposome-mediated transfection, microprojectile-mediated delivery, electroporation, and the like. The transfected cells can be selected and propagated to provide recombinant host cells that comprise the expression vector stably integrated in the host cell genome. Techniques for introducing vectors into eukaryotic cells and techniques for selecting such stable transformants using dominant selectable markers are well known in the art.

[0048] The use of transgenic animals to express heterologous proteins is also well-known. Introduction of a recombinant DNA into the fertilized egg of an animal (e.g., a mammal) may be accomplished using any number of standard techniques in transgenic animal technology. See, e.g., Hogan et al., Manipulating the Mouse Embryo: A Laboratory Manual, Cold Spring Harbor Laboratory Press, Cold Spring Harbor, N.Y., 1986; and U.S. Pat. No. 5,811,634. Once the recombinant DNA is introduced into the egg, the egg is incubated for a short period of time and is then transferred into a pseudopregnant animal of the same species from which the egg was obtained. While the entire animal can be used as an expression system for the fusion proteins of the invention, typically, the fusion protein accumulates in products of the animal, from which it can be harvested without injury to the animal. In preferred embodiments, the fusion protein accumulates in milk, eggs, hair, blood, or urine. If the fusion protein is to be accumulated in the milk of the animal, suitable mammals are ruminants, ungulates, domesticated mammals, and dairy animals. Particularly preferred animals are goats, sheep, camels, cows, pigs, horses, oxen, and llamas. Methods for generating transgenic cows that accumulate a recombinant peptide in their milk are well known: see, Newton (1999, J. Immunol. Methods 231:159-167), Ebert et al. (1991, Biotechnology 9: 835-838), and U.S. Patent Nos. 6,210,736, 5,849,992, 5,843,705, 5,827,690, 6,222,094.

[0049] The fusion proteins of the invention can also be expressed in other higher eukaryotic cells, such as avian, insect, fungal, yeast, or plant cells. The baculovirus system provides an efficient means to introduce cloned genes into insect cells. Fungal cells, including yeast cells, can also be used to express the genes described herein. Yeast species of particular interest in this regard include *Saccharomyces cerevisiae, Pichia pastoris,* and *Pichia methanolica.* Suitable promoters for expression in yeast include promoters from *GAL1* (galactose), *PGK* (phosphoglycerate kinase), *ADH* (alcohol dehydrogenase), *AOX1* (alcohol oxidase), HIS4 (histidinol dehydrogenase), and the like. Expression vectors can also be introduced into whole plants (*e.g.,* tobacco plants), plant protoplasts, intact plant tissues, or isolated plant cells. Methods for introducing expression vectors into plant tissue include the direct infection or co-cultivation of plant tissue with *Agrobacterium tumefaciens,* microprojectile-mediated delivery, DNA injection, electroporation, and the like.

[0050] Alternatively, genes encoding the polypeptides of the present invention can be expressed in prokaryotic host cells. Suitable prokaryotic hosts include *E. coli* and *Bacillus subtilus.* Suitable strains of *E. coli* include BL21(DE3), BL21(DE3)pLysS, BL21(DE3)pLysE, DH1, DH4I, DH5, DH5I, DH5IF', DH5IMCR, DH10B, DH10B/p3, DH11S, C600, HB101, JM101, JM105, JM109, JM110, K38, RR1, Y1088, Y1089, CSH18, ER1451, and ER1647 (see, for example, Brown (ed.), Molecular Biology Labfax (Academic Press 1991)). Suitable strains of *Bacillus subtilus* include BR151, YB886, MI119, MI120, and B170 (see, for example, Hardy, "Bacillus Cloning Methods," in DNA Cloning: A Practical Approach, Glover (ed.) (IRL Press 1985)).

[0051] Methods for expressing proteins in prokaryotic hosts are well-known to those of skill in the art (see, for example,

Williams et al., "Expression of foreign proteins in E. coli using plasmid vectors and purification of specific polyclonal antibodies," in DNA Cloning 2: Expression Systems, 2nd Edition, Glover et al. (eds.), page 15 (Oxford University Press 1995), Ward et al., "Genetic Manipulation and Expression of Antibodies," in Monoclonal Antibodies: Principles and Applications, page 137 (Wiley-Liss, Inc. 1995), and Georgiou, "Expression of Proteins in Bacteria," in Proteins Engineering: Principles and Practice, Cleland et al. (eds.), page 101 (John Wiley & Sons, Inc. 1996)).

[0052] Once expressed, the fusion proteins of the present invention can be purified according to standard procedures of the art, including ammonium sulfate precipitation, fraction column chromatography, gel electrophoresis and the like.

IMMUNOGENIC COMPOSITIONS

[0053] Purified or partially purified fusion proteins of the invention may be formulated as a vaccine (also referred to as an "immunogenic composition") according to methods well known in the art. Such compositions may include adjuvants to enhance immune responses. The optimal ratios of each component in the formulation may be determined by techniques well known to those skilled in the art. The immunogenic compositions may be administered to a patient according to standard techniques well-known to those of skill in the art. The patient can be a human, or non-human animal (*e.g.,* cattle, horses, pigs, dogs, and cats).

[0054] The preparation and use of immunogenic compositions are well known to those of skill in the art. Liquid pharmaceutical compositions generally include a liquid carrier such as water, petroleum, animal or vegetable oils, mineral oil or synthetic oil. Physiological saline solution, dextrose or other saccharide solution or glycols such as ethylene glycol, propylene glycol or polyethylene glycol may be included.

[0055] The polynucleotides encoding the fusion proteins of the invention can also be administered to the patient. Typically, an expression cassette suitable for driving expression in human cells is prepared. This approach is described, for instance, in Wolff (1990) Science 247:1465-1468; U.S. Patent Nos. 5,580,859 and 5,589,466.

[0056] The compositions are suitable for single administrations or a series of administrations. When given as a series, inoculations subsequent to the initial administration are given to boost the immune response and are typically referred to as booster inoculations. The compositions of the invention can be used as a boosting composition primed by antigen using any of a variety of different priming compositions, or as the priming composition. Thus, one aspect of the present invention provides a method of inducing and/or boosting an immune response to an antigen in an individual.

[0057] The timing of the administration of boosting compositions is well within the skill in the art. Boosting composition are generally administered weeks or months after administration of the priming composition, for example, about 2-3 weeks or 4 weeks, or 8 weeks, or 16 weeks, or 20 weeks, or 24 weeks, or 28 weeks, or 32 weeks.

[0058] The compositions of the invention may comprise other Filovirus antigens or the priming or boosting inoculations may comprise other antigens. The other antigens used in combination with the fusion proteins of the invention are not critical to the invention and may be, for example, Filovirus antigens, nucleic acids expressing them, virus like particles (VLPs) or replication deficient or competent viral vectors that comprise the nucleic acids, such as the prior art vaccines discussed above. Such viral vectors include, for example, adenoviral vectors, vaccinia virus vectors, avipox vector such as fowlpox or canarypox, herpes virus vectors, a vesicular stomatitis virus vectors, or alphavirus vectors. One of skill will recognize that the immunogenic compositions of the invention may comprise multiple antigens and vectors.

[0059] The antigens in the respective priming and boosting compositions (however many boosting compositions are employed) need not be identical, but should share epitopes. The antigen may correspond to a complete antigen in a target pathogen or cell, or a fragment thereof. Peptide epitopes or artificial strings of epitopes may be employed, more efficiently cutting out unnecessary protein sequence in the antigen and encoding sequence in the vector or vectors. For example, one or more additional epitopes may be included, for instance epitopes which are recognized by T helper cells, especially epitopes recognized in individuals of different HLA types.

[0060] As noted above, the immunogenic compositions of the invention may comprise adjuvants. Adjuvants suitable for co-administration in accordance with the present invention should be ones that are potentially safe, well tolerated and effective in people including QS-21, Detox-PC, MPL-SE, MoGM-CSF, TiterMax-G, CRL- 1005, GERBU, TERamide, PSC97B, Adjumer, PG-026, GSK-I, GcMAF, B-alethine, MPC-026, Adjuvax, CpG ODN, Betafectin, Alum, and MF59 (see Kim et al., 2000 Vaccine 18:597 and references therein).

[0061] Other adjuvants that may be administered include lectins, growth factors, cytokines and lymphokines such as alpha-interferon, gamma interferon, platelet derived growth factor (PDGF), granulocyte-colony stimulating factor (gCSF), granulocyte macrophage colony stimulating factor (gMCSF), tumor necrosis factor (TNF), epidermal growth factor (EGF), IL-I, IL-2, IL-4, IL-6, IL-8, IL-IO, and IL-12 or encoding nucleic acids therefore.

[0062] As noted above, the compositions of the invention may comprise a pharmaceutically acceptable excipient, carrier, buffer, stabilizer or other materials well known to those skilled in the art. Such materials should be non-toxic and should not interfere with the efficacy of the active ingredient. The precise nature of the carrier or other material may depend on the route of administration, e.g., oral, intravenous, cutaneous or subcutaneous, intramucosal (e.g., gut), intranasal, intramuscular, or intraperitoneal routes. Adiminstration is typically intradermal, *e.g.,* subcutaneous or intra-

muscular.

[0063] Intramuscular administration of the immunogenic compositions may be achieved by using a needle to inject a suspension of the fusion protein or nucleic acid encoding it. An alternative is the use of a needless injection device to administer the composition (using, e.g., Biojector(TM)) or a freeze-dried powder containing the vaccine.

[0064] For intravenous, cutaneous or subcutaneous injection, or injection at the site of affliction, the fusion protein will be in the form of a parenterally acceptable aqueous solution which is pyrogen-free and has suitable pH, isotonicity and stability. Those of skill in the art are well able to prepare suitable solutions using, for example, isotonic vehicles such as Sodium Chloride Injection, Ringer's Injection, Lactated Ringer's Injection. Preservatives, stabilizers, buffers, antioxidants and/or other additives may be included, as required. A slow-release formulation may also be employed

[0065] Typically, administration will have a prophylactic aim to generate an immune response against a Filovirus antigen before infection or development of symptoms. Diseases and disorders that may be treated or prevented in accordance with the present invention include those in which an immune response may play a protective or therapeutic role. In other embodiments, the Filovirus glycoprotein Fc fusion proteins can be administered for post-exposure prophylactics.

[0066] The immunogenic compositions containing the fusion proteins or polynucleotides encoding them are administered to a subject, giving rise to an anti-Filovirus immune response in the subject. An amount of a composition sufficient to in induce a detectable immune response is defined to be an "immunologically effective dose." As shown below, the immunogenic compositions of the invention induce an antibody response, as well as a CD8+ T cell immune response. In a typical embodiment the immune response is a protective immune response.

[0067] The actual amount administered, and rate and time-course of administration, will depend on the nature and severity of what is being treated. Prescription of treatment, e.g., decisions on dosage etc., is within the responsibility of general practitioners and other medical doctors, or in a veterinary context a veterinarian, and typically takes account of the disorder to be treated, the condition of the individual patient, the site of delivery, the method of administration and other factors known to practitioners. Examples of the techniques and protocols mentioned above can be found in Remington's Pharmaceutical Sciences, 16th edition, Osol, A. ed., 1980.

[0068] Following production of Filovirus glycoprotein Fc fusion proteins and optional formulation of such particles into compositions, the fusion proteins may be administered to an individual, particularly human or other primate. Administration may be to humans, or another mammal, e.g., mouse, rat, hamster, guinea pig, rabbit, sheep, goat, pig, horse, cow, donkey, dog or cat. Delivery to a non-human mammal need not be for a therapeutic purpose, but may be for use in an experimental context, for instance in investigation of mechanisms of immune responses to the fusion protein.

[0069] In one exemplary regimen, the fusion protein is administered (*e.g.,* intramuscularly) at a dose of 10 micrograms to 1 milligrams/injection. A boost can be administered up to 4 weeks later. The composition may, if desired, be presented in a kit, pack or dispenser, which may contain one or more unit dosage forms containing the active ingredient. The kit, for example, may comprise metal or plastic foil, such as a blister pack. The kit, pack, or dispenser may be accompanied by instructions for administration.

[0070] The compositions of the invention may be administered alone or in combination with other treatments, either simultaneously or sequentially dependent upon the condition to be treated.

DETECTION OF IMMUNE RESPONSES

[0071] The fusion proteins of the invention are useful in the detection of Filovirus infection. Methods for detecting humoral or cellular immune responses in biological samples are well known in the art. As used herein, a "biological sample" is any lymphocyte or antibody-containing sample obtained from a patient. For example, the sample can be whole blood, sputum, serum, plasma, saliva cerebrospinal fluid or urine. The proteins of the invention are used in an assay, for example as described below, to determine the presence or absence of antibodies or immune cells (*e.g.,* lymphocytes, CD4+ T-cells, CD8+ T-cells, B-cells, NK cells, mast cells, antigen presenting cells) reactive with Filovirus antigens. The presence of such antibodies or immune cells indicates previous sensitization to Filoviral antigens which may be indicative of Filovirus infection.

[0072] There are a variety of assay formats known to those of ordinary skill in the art for using one or more polypeptides to detect antibodies in a sample. For example, the assay may involve the use of a fusion protein immobilized on a solid support to bind to and remove the antibodies from the sample. The assay may also involve the capture of the fusion protein by an antibody or binding protein (e.g., protein A, protein G, protein A/G, avidin, streptavidin, etc.) bound to a solid support. The assay may involve the labeling of the fusion protein with small molecules such as biotin, enzymes, or fluorophores. Alternatively, antibodies from patients could be bound to a solid phase using binding proteins or type specific antibodies (e.g., anti-human IgM or IgG antibodies), followed by treatment with the labeled or unlabeled fusion protein (FiloGP-Fc), and finally detecting the bound fusion protein with a conjugated antibody and/or a binding protein (e.g., avidin-FITC, avidin-peroxidase, etc.). The fusion protein can be isolated or expressed on the surface of a recombinant virus (*e.g.,* Vesicular Stomatitis Virus). The bound antibody may then be detected using a detection reagent that

contains a reporter group. Suitable detection reagents include antibodies that bind to the solid phase bound fusion protein or antibody/polypeptide complex or to free polypeptide labeled with a reporter group (*e.g.,* in a semi-competitive assay). Alternatively, a competitive assay may be utilized, in which an antibody that binds to the polypeptide is labeled with a reporter group and allowed to bind to the immobilized antigen after incubation of the antigen with the sample. The extent to which components of the sample inhibit the binding of the labeled antibody to the polypeptide is indicative of the reactivity of the sample with the immobilized polypeptide. In certain embodiments, the assay is an enzyme linked immunosorbent assay (ELISA), chemiluminescent assay, or fluorescence assay.

[0073] Methods for detecting cellular immune responses are also well known. In such assays antigen presenting cells, immune cells (*e.g.,* $CD8^+$ T-cells, CD4+ T-cells, B-cells, etc.) and fusion proteins of the invention are incubated under appropriate conditions to induce proliferation or activation of immune effector cells (e.g.,$CD8^+$ T-cells, CD4+ T-cells, B-cells, NK and iNKT cells, etc) specific to the Filovirus protein. The antigen-specific responses of induced immune effector cells (e.g., helper T-cells, CTLs, B-cells, NK, NKT, etc.) can be detected by a number of techniques (*e.g.*, by a ^{51}Cr release assay, ^{3}H-thymidine incorporation, CFSE and other FACS-analysis proliferation assays, cytokine intracellular staining and FACS analysis, ELISPOT, detection of secreted cytokines such as INF-γ).

[0074] The ability of antibodies in a sample to neutralize Filovirus infection can be tested. This can be carried out, for example, using a plaque-reduction test or endpoint dilution assay based on the neutralization of a recombinant virus expressing a Filovirus GP. Also, neutralization can be determined by ELISA, microscopy analysis, or FACS analysis staining infected cells with anti-virus antibodies conjugated with small molecules, enzymes, or fluorophores and/or secondary antibodies or binding proteins (e.g., avidin) conjugated to enzymes or fluorophores. Alternatively, neutralization of recombinant viruses expressing Filovirus GP and containing fluorescent protein genes (e.g., GFP, YFP, etc.) could be determined by the reduction in fluorescent infected cells using fluorescent microscopy analysis or FACS analysis. For example, a recombinant Vesicular Stomatitis Virus (VSV) expressing a Filoviurs GP can be used in such an assay. As shown below, since neutralizing antibodies against Filoviruses are directed towards GP, the only envelope glycoprotein at the cell surface of the virus, neutralization of recombinant VSV expressing such a protein mimics neutralization of Filoviruses. Total antibodies can also be detected by a VSV particle ELISA coating plates with a recombinant Vesicular Stomatitis Virus (VSV) expressing a Filoviurs GP. Methods for carrying out neutralization assays are well known to those of skill in the art. An exemplary assay is described in detail below.

[0075] The invention having been described, the following examples are offered by way of illustration and not limitation.

EXAMPLES

[0076] The following examples are offered to illustrate, but not to limit the claimed invention.

EXAMPLE 1

1. Materials and methods

1.1. Cells lines

[0077] Chinese hamster ovary (CHO) cells deficient in the enzyme dihydrofolate reductase ($dhfr^-$) were obtained from the American Type Culture Collection and expanded in growth medium consisting of Iscove's medium containing 10% fetal bovine serum (FBS) (Silberstein et al., J Virol 2001 Jan;75(2):717-25). Human embryonic kidney HEK293-H cells (Invitrogen) were maintained in Dulbecco's modified Eagle medium (DMEM) supplemented with 10% FBS. Vero E6 cells were grown in Eagle's minimal essential medium (MEM) supplemented with 10% FBS. Baby hamster kidney cells (BHK-21) were maintained in DMEM medium supplemented with 5% FBS. The BSR-T7 cells, which are BHK-21 cells that express bacteriophage T7 RNA-polymerase Buchholz et al., J Virol 1999 Jan;73(1):251-9), was kindly provided by Dr. K. Conzelmann (Pettenkoffer Institute, Munich, Germany) and maintained in DMEM medium supplemented with 5% FBS and 1 mg/ml geneticin (Invitrogen).

1.2. Mice

[0078] C57BL/6 and BALB/c mice were obtained from the National Cancer Institute, Frederick Cancer Research and Development Center (Frederick, MD). All mice were housed in micro-isolator cages and provided standard rodent feed and water ad libitum. Blood samples were obtained from the lateral tail vein. Research was conducted in compliance with the Animal Welfare Act and other federal statutes and regulations relating to animals and experiments involving animals and adheres to principles stated in the guide for the Care and Use of Laboratory Animals, National Research Council, 1996. The facility where these researches were conducted is fully accredited by the Association for Assessment and Accreditation of Laboratory Animal Care International. The animal protocols were approved by CBER-FDA or US-

AMRIID Institutional Animal Care and Use Committees (IACUC).

1.3. Cloning procedures

[0079] The cDNA of the Zaire Ebola virus (ZEBOV) glycoprotein (GP), Mayinga strain (GenBank accession no. AF272001), in pVR-1012-ZEBOV-GP was kindly provided by Dr. Gary Nabel, Vaccine Research Center, NIH, Bethesda, MD Yang et al., Nat Med 2000 Aug;6(8):886-9). The glycoprotein gene has eight adenosine (A) residues at the RNA editing site needed to produce the full-length ZEBOV GP. The following plasmids were constructed using standard technique of genetic engineering:

1.3.1. pEF1-EBOV GP

[0080] The GP region was excised from pVR-1012-ZEBOV-GP using NcoI and Asp718 (Roche Applied Science) restriction enzymes, filled in with DNA polymerase Klenow (New Engalnd Biolabs) enzyme to create blunt ends and subsequently cloned into the EcoRV site of the mammalian expression plasmid pEF1/Myc-His-B (Invitrogen). The resulting plasmid was termed pEF1-EBOV-GP.

1.3.2. pEF-ZEBOVGP-Fc

[0081] To construct a plasmid for the expression of an ZEBOV GP Fc fusion protein, a PCR fragment coding for amino acids 1 to 637 (GenBank accession no. U23187) of the ZEBOV GP ectodomain was amplified from pVR-1012-ZEBOV-GP using synthetic oligonucleotides GP/SalI (5'-GTCGACAGTATGGGCGTTACAGGAATATTGCAGTTA-3'), which contains SalI site before the sequence coding for the signal peptide GP, and GP/Flag/SpeI (5'-ACTAGTACTCACCTCCCTTGTCATCGTCGTCCTTGTAGTCTCCACCGCCGTCCGGAAG GGTTTTATCAACAAA-3'), which contains an SpeI site followed by an artificial splicing donor site, the coding sequence for the FLAG tag peptide DTKDDDDK, and nucleotides 1887 to 1911 of GP. This PCR fragment was cloned into the SalI and SpeI sites of pEF-ICAM5(1-2) Fc replacing the ICAM 1 cDNA fragment and in-frame with the Fc fragment of human IgG1 Silberstein et al., J Virol 2001, *supra.* Silent mutations (GTCGAC to GTAGAC, and CTAGTT to CTCGTT) were introduced into the GP coding sequence to eliminate internal SalI and SpeI restriction sites. The resulting plasmid was termed pEF-ZEBOVGP-Fc.

1.3.3. pEF-FLAG-Fc

[0082] To construct a plasmid for the expression of the Fc fragment of human IgG1, we replaced the ICAM 1 sequence in pEF-ICAM5(1-2)Fc with a cDNA fragment coding for the signal peptide of the ZEBOV GP and a FLAG tag. To do so, we amplified a PCR fragment coding for amino acids 1-32 of the ZEBOV GP signal peptide using pVR-1012-ZEBOV-GP as a template and synthetic oligonucleotides GP/SalI (see above) and SP/Flag/SpeI (5'-ACTAGTACTCACCTCCCTT-GTCATCGTCGTCCTTGTAGTCTCCACCGCC-GGAAAATGTTCTTTGGAAAAGGAT-3'), which codes for a FLAG tag, nucleotides 73 to 96 of the GP cDNA, and an SpeI restriction site. The amplified PCR fragment was digested with SalI and SpeI restriction enzymes and cloned into pEF-ICAM5(1-2)Fc digested with the same enzymes. The resulting plasmid was termed pEF-FLAG-Fc.

1.3.4. pVSV-ZEBOVGP

[0083] To construct replication-competent VSV-G deleted recombinant Vesicular Stomatitis Virus (VSV) expressing the ZEBOV GP (rVSV-ZEBOVGP), a PCR fragment coding for GP of ZEBOV (amino acids 1-676) amplified from pVR-1012-ZEBOV-GP using oligonucleotides GP/NheI(+) (5'ACTAGTAGTATGGGCGTTACAGGAATATTGCAGTTA-3'), which is identical to GP/SalI except for the SalI site that was substituted for an NheI restriction, and antisense primer GP/NheI (-) (5'-GCTAGCCTAAAAGACAAATTTGCATATACAGAA-3'), was cut with NheI and cloned into NheI cut pVS-VΔG. The resulting plasmid was termed pVSV-ZEBOVGP.

1.4 Selection of HEK-293-H stable transfectants expressing ZEBOV GP at the cell surface

[0084] HEK293-H cells were transfected with pEFI-ZEBOV-GP or vector pEF1 using Fugene 6 reagent (Roche Applied Science) as suggested by the manufacturer, and stable transfectants were selected with 350 μg/mL geneticin and termed HEK293-ZEBOVGP or HEK293 cells. Single cell clones were produced and analyzed by flow cytometry using anti-ZEBOV GP monoclonal antibody (mAb) 13F6-1-2 (Wilson et al., Science 2000 Mar 3;287(5458):1664-6, Lee et al., J Mol Biol 2008 Jan 4;375(1):202-16) to select stable transfectants expressing high levels of ZEBOV GP at the cell surface.

1.5 Production and purification of Fc fusion proteins

[0085] Fc fusion proteins were produced in CHO cell transfectants. To do so, CHO dhfr$^-$ cells were cotransfected with 0.45 μg of pDHIP and 3.5 μg of pEF-ZEBOVGP-Fc or pEF-Fc using the Fugene 6 reagent as described previously Silberstein et al., J Virol 2001, *supra.* Briefly, cell transfectants were grown in Iscove's medium containing 10% FBS supplemented with hypoxanthine and thymidine for 48 h at 37°C, split 1:10, and selected in Iscove's medium containing dialyzed FBS without supplements. After 14 days of selection, single cell clones were obtained by end-point dilution in 96-well plates. The supernatants of 56 single-cell clones were assayed for the expression of fusion proteins by a capture ELISA in 96-well plates coated with goat anti-human Fc antibody and staining with anti-GP mAb and HRP-conjugated goat anti-mouse antibody (Ab). Overexpression of the Fc fusion proteins was achieved by a stepwise increase in the concentration of methotrexate (MTX). Cells reached a maximum level expression of ZEBOVGP-Fc and FLAG-Fc at 0.08 and 0.32 μM MTX, respectively.

[0086] Fc fusion proteins were purified as described previously Silberstein et al., J Virol 2001, *supra.* Briefly, CHO cells expressing recombinant proteins were grown in Iscove's medium containing 10% FBS for 3 days, monolayers were washed twice with Iscove's medium, and grown in serum-free OptiMEM medium (Invitrogen). Supernatants were harvested 2-3 times at 24 h intervals, clarified at 3,000xg, and stored at -20°C. Fc fusion protein in the OptiMEM supernatant was purified by affinity chromatography in protein A-agarose columns. Eluted fractions were analyzed by denaturing sodium dodecyl sulfate-polyacrylamide gel electrophoresis (SDS-PAGE), and the fractions containing the Fc fusion proteins were pooled, concentrated using Amicon ultra column (Millipore), and washed with PBS.

1.6 Western blot analysis

[0087] Purified proteins were fractionated in denaturing SDS-PAGE, transferred to Immobilon-P polyvinylidene difluoride (PVDF) membranes (Millipore), and stained with a 1:1,000 dilution of mouse anti-ZEBOV GP 13F6-1-2 mAb (USAMRIID), mouse anti-FLAG M2 mAb (Sigma Chemical Co.), or goat anti-human IgG Fc Ab, and a 1:3,000 dilution of phosphatase-labeled goat anti-mouse or rabbit anti-goat Ab. The Western blot was developed with 5-bromo-4-chloro-3-indolylphosphate-nitrobluetetrazolium substrate (Kpl Inc.) as recommended by the manufacturer.

1.7. Rescue of rVSV-ZEBOVGP

[0088] To generate recombinant VSV carrying the ZEBOV GP (rVSV-ZEBOVGP), we used the reverse genetics system developed by Dr. John Rose (Yale Univ., New Haven, CT), who kindly provided us with plasmid coding for the VSV full-length genome [pVSVFL(+)], VSV-G deleted VSV genome (pVSVΔG), VSV nucleoprotein (pBS-N), VSV phosphoprotein (pBS-P), and VSV-L polymerase (pBS-L) [27] . To do so, BSR-T7 cells grown to 80-90% confluency in 6-well plates were cotransfected with 0.25 μg pBS-N, 0.6 μg pBS-P, 0.13 μg pBS-L, and 1 μg pVSV-ZEBOVGP or positive control pVSVFL(+) using 5 ul Lipofectamine 2000 (Invitrogen) as a facilitator per well (Lawson et al., Proc Natl Acad Sci USA 1995 May 9;92(10):4477-81; Garbutt et al., J Virol 2004 May;78(10):5458-65). After 48 h of incubation at 37°C, supernatants were harvested and used to infect 50% confluent BHK-21 cells. After monolayers developed cytopathic effect (CPE), supernatants containing rVSV-ZEBOVGP or VSV were collected, titrated in Vero E6 cells, and stored at -80°C.

1.8. Enterokinase cleavage of ZEBOVGP-Fc protein

[0089] The Fc fragment of ZEBOVGP-Fc was removed by treatment with 0.4 μg of restriction protease enterokinase (New England Biolabs) per mg of fusion protein, which cleaved the FLAG peptide that was engineered between the GP and Fc fragments. The digestion product was analyzed by FPLC on a Superdex200 column (GE Healthcare) under non-denaturing conditions. The collected fractions were analyzed by denaturing SDS-PAGE and Western blot analysis staining with anti-ZEBOV GP mAb 13F6-1-2 or anti-Fc fragment Ab and appropriate phosphatase-conjugated secondary Ab.

1.9. Vaccination and ZEBOV challenge

[0090] Six-to-eight week old C57BL/6 mice were vaccinated intraperitoneally (i.p.) with 100 μg of ZEBOVGP-Fc (n = 8) or with 100 μg of Fc (n = 8) in complete Freunds adjuvant. At 21, 45 and 60 days post inoculation, animals were boosted with 25 μg of the corresponding protein in incomplete Freund adjuvant. Serum samples were obtained from each mouse prior to challenge. Mice were challenged 2 weeks after the final vaccination by i.p. injection with 1,000 pfu of mouse-adapted ZEBOV diluted in PBS (Bray et al., J Infect Dis 1998 Sep; 178(3):651-6; Bradfute et al., J Immunol 2010 Jan 1;184(1):327-35). All ZEBOV-infected mice were handled under maximum containment in a biosafety level-4

(BSL4) laboratory at the U.S. Army Medical Research Institute of Infectious Diseases, Frederick, MD.

1.10. Antibody titer determination

[0091] Anti-ZEBOV specific Ab was analyzed by ELISA as described previously (Hevey et al., Virology 1998 Nov 10;251(1):28-37). Sera from vaccinated mice were titrated by endpoint dilution ELISA on 96-well plates coated with sucrose purified inactivated ZEBOV virions and stained with peroxidase-labeled goat anti-mouse IgG Ab. Titers were determined as the highest dilution at which the absorbance of the sample was greater (two times) than non-specific or no-antigen wells (Warfield et al., Vaccine 2004 Sep 3;22(25-26):3495-502). Anti-ZEBOV Ab titers were also determined in parallel using 96-well plates coated with rVSV-ZEBOVGP. Plates coated with VSV were used as specificity control. Sera from vaccinated mice were titrated on the plates, stained with peroxidase-labeled goat anti-mouse IgG Ab, and Ab titers were determined as described above.

[0092] For FACS analysis, live HEK293-ZEBOVGP cells expressing ZEBOV GP at the surface or control HEK293 cells transfected with empty vector were stained with 1 μl of sera from vaccinated followed by a PE-conjugated anti-mouse Ab (BD Biosciences). Cells were analyzed in a FACSCanto II flow cytometer (BD Biosciences).

1.11. rVSV-ZEBOVGP plaque reduction assay

[0093] Anti-ZEBOV neutralizing antibodies were analyzed by a plaque reduction assay. Five-fold dilutions of sera from vaccinated mice were mixed with 100 pfu of rVSV-ZEBOVGP or control VSV. Samples were incubated at 37°C for 1 h in the presence of 5% guinea pig serum complement and a standard plaque assay was performed in Vero E6 cells overlayed with medium containing 1% bactoagar (DIFCO). The percent of plaque reduction was calculated by comparing the number of pfu in the neutralized sample versus the input virus Wilson *et al.,* and Warfield *et al., supra.*

1.12. Intracellular cytokine staining

[0094] Intracellular cytokine staining was performed by incubating splenocytes from vaccinated mice with EBOV GP peptides or ZEBOVGP-Fc as described (Olinger et al., J Virol 2005 Nov;79(22):14189-96). Briefly, splenocytes were isolated by passing spleens through a mesh filtration, washed, and cultured in RPMI 1640 medium containing 10% FBS, 2mM L-glutamine, 1mM HEPES, and 0.1 mM nonessential amino acids. Splenocytes were stimulated with 1 μg/ml of three EBOV GP specific peptides (LYDRLASTV, VSTGTGPGAGDFAFHK, and EYLFEVDNL) (Olinger *et al., supra* and Warfield et al., J Immunol 2005 Jul 15;175(2):1184-91) or an unrelated peptide (KINSTALL) as a negative control. Alternatively, splenocytes were stimulated with 10 μg/ml of ZEBOVGP-Fc or FC protein. After stimulation and 1 h of incubation at 37°C in the presence of interleukin-2, brefeldin A was added and cells were incubated for 5 h before staining with the APC-conjugated anti-mouse CD8 mAb clone RM4-5 (Invitrogen). Cells were then washed, fixed, and permeabilized using the cytofix/cytoperm kit according to the manufacturer's instructions (BD Biosciences). Intracellular IFN-γ was stained with PE-conjugated rat anti-mouse IFN-γ mAb clone XMG1.2 (Invitrogen), and analyzed by flow cytometry in a FACSCanto II instrument.

1.13. Statistical analysis

[0095] Statistical significance between two means was determined by the unpaired Student's t-test and calculated using Graph Pad software, and p-values were included in the text and figures.

2. Results

2.1. ZEBOVGP-Fc fusion protein undergoes furin cleavage and the complex processing of native ZEBOV GP

[0096] To express large amounts of soluble ZEBOV GP for purification, characterization and immunization purposes, we developed a stable CHO cell line expressing the extracellular domain of ZEBOV GP fused to the human IgG1 Fc fragment. We reasoned that the Fc fragment would increase the yield, simplify purification, and maximize the *in vitro* and *in vivo* stability of the recombinant soluble protein (Chamow et al., Trends Biotechnol 1996 Feb;14(2):52-60). We also included a FLAG tag epitope between the ZEBOV GP and the Fc fragment to monitor the expression of the chimeric protein with anti-FLAG M2 mAb and also to be able to cleave off the Fc fragment using enterokinase, a restriction protease that cuts at the FLAG tag site. To do so, we cotransfected CHO dhfr- cells with pDHIP, a plasmid coding for the dihydrofolate reductase (DHFR) gene, and pEF-ZEBOVGP-Fc, the construct coding for the ZEBOV GP ectodomain fused to the Fc fragment of IgG1 (Fig. 1A). As a control, we also cotransfected CHO dhfr- cells with pDHIP and pEF-FLAG-Fc, a plasmid coding for the same Fc fragment containing a FLAG tag at the N-terminus. Single cell clones were

selected and over expression of the recombinant protein was achieved by increasing the concentration of MTX (Silberstein *et al., supra*). A CHO cell clone that produced the highest ZEBOVGP-Fc or FLAG-Fc protein yield as measured by ELISA were used for protein production. Protein A purified proteins were analyzed by SDS-PAGE under reducing conditions followed by Coomassie blue staining (Fig. 1B). Two major bands were observed in ZEBOVGP-Fc: a broad band of approximately 130-150 kDa characteristic of highly glycosylated proteins with the expected molecular weight of GP1, and a smaller band of approximately 60 kDa with the expected molecular weight of GP2-Fc. Additional minor bands corresponding to partially glycosylated or degraded proteins were also observed in the ZEBOVGP-Fc lane. The control FLAG-Fc protein migrated as a 36 kDa band. Western blot analysis probing with anti-GP1 mAb 13F6-1-2, anti-FLAG mAb M2, and anti-Fc Ab confirmed the identity of the GP1, GP2-Fc, and FLAG-Fc bands (Fig. 1C). Our data revealed that the ZEBOVGP-Fc fusion protein underwent the complex postranslational modifications of the mature GP including the furin cleavage between GP1 and GP2.

2.2. ZEBOV GP in ZEBOVGP-Fc assembles into homotrimers

[0097] Analysis of purified ZEBOVGP-Fc (50 μg) by size exclusion chromatography through a Superdex 200 10/300 GL column using an AKTA FPLC system (GE) revealed that this fusion protein migrated as a main peak of approximately 1,000 kDa with a broad shoulder consistent with the highly glycosylated nature of GP as observed by SDS-PAGE analysis (Fig. 2A). Since GP forms homotrimers at the virus and cell surface, we hypothesized that the large ZEBOVGP-Fc complexes analysis could be due to GP homotrimer formation, and that 6 copies of ZEBOV-Fc could form 2 homotrimers associated by the disulfide bonds of the Fc fragments, which would have a size of approximately 1,000-1,200 kDa. To test our hypothesis, we digested the ZEBOVGP-Fc (100 μg) with the restriction protease enterokinase (40 ng), which cleaves at the FLAG peptide inserted between GP2 and the Fc fragment. Size exclusion chromatography of this digested product revealed 3 main peaks of approximately 600, 140, 50 kDa (Fig. 2A). We determined that the 140 kDa peak corresponded to a carrier protein present in the enterokinase enzyme preparation. The 600 kDa peak was consistent with the migration of a GP homotrimer formed by GP1 (130-150 kDa) and GP2 (25 kDa). The 50 kDa peak had the expected size of an Fc fragment (2 chains of 25 kDa associated by disulfide bonds), and comigrated with the Fc fragment ran under the same conditions (data not shown). Western blot analysis of the 600 and 50 kDa peaks probed with anti-GP1 and anti-Fc antibodies confirmed that the 600 kDa peak corresponded to the GP extracellular domain and the 50 kDa peak corresponded to the Fc fragment (Fig. 2B). These results clearly show that the GP in ZEBOVGP-Fc formed homotrimers resembling the conformation of the natural form of GP expressed on the viral particle and cell surface (Hood et al., J Virol 2010 Mar;84(6):2972-82).

2.3. ZEBOVGP-Fc elicits anti-ZEBOV humoral response in vaccinated mice

[0098] To determine whether ZEBOVGP-Fc was immunogenic, we vaccinated eight C57BL/6 mice with ZEBOVGP-Fc or control FLAG-Fc and tested anti-GP antibodies by ELISA 2 weeks after the final boost. The 8 mice vaccinated with ZEBOVGP-Fc developed anti-ZEBOV GP antibody titers of 1:64,000 to 1:4,000 as measured by an ELISA assay in 96-well plates coated with killed irradiated ZEBOV (Fig. 3A). We also performed a similar ELISA using 96-well plates coated with a purified recombinant VSV containing the ZEBOV GP, rVSV-ZEBOVGP, or wild type VSV as specificity control. The titers determined in the rVSV-ZEBOVGP ELISA were identical to the titers obtained in the killed irradiated ZEBOV ELISA. Sera from control FLAG-Fc vaccinated mice did not react with irradiated ZEBOV or rVSV-ZEBOVGP indicating that the antibodies detected in the vaccinated animals were specific to ZEBOV GP. Moreover, neither sera from ZEBOVGP-Fc nor FLAG-Fc vaccinated animals reacted with wt VSV indicating that the antibodies detected in the ELISA were highly specific to ZEBOV GP.

[0099] The sera of the vaccinated mice were also tested by FACS analysis on live HEK293 cells expressing EBOV GP protein (HEK293-ZEBOVGP) at the cell surface or vector-transfected cells (HEK293). Sera from ZEBOVGP-Fc immunized mice reacted with the HEK293-ZEBOVGP cells but not with HEK293 cells (Fig. 3B). It should be pointed out that one of the immunized animals reacted poorly with the ZEBOV GP (animal #8). As expected, sera from the FLAG-Fc-vaccinated animals did not react with HEK293-ZEBOVGP or HEK293 cells, and anti-ZEBOV GP mAb 13F6-1-2 reacted only with HEK293-ZEBOVGP cells. These data are consistent with the ELISA data and demonstrated that anti-ZEBOV GP antibodies in the ZEBOVGP-Fc vaccinated animals react with native ZEBOV GP.

2.4. Anti-ZEBOVGP antibodies neutralize recombinant VSV containing the ZEBOV GP.

[0100] Since the vaccinated mice developed anti-ZEBOV GP antibodies, it was of interest to determine whether these antibodies were capable of neutralizing virus. To do so, we performed plaque-reduction test based on the neutralization of rVSV-ZEBOVGP, a replication-competent recombinant VSV-G deleted VSV containing the ZEBOV GP that infect cells via the ZEBOV GP (Lawson *et al.,* and Garbutt *et al., supra*). Since neutralizing antibodies against ZEBOV are

directed towards GP, the only envelope glycoprotein at the cell surface of the virus, neutralization of rVSV-ZEBOVGP mimics neutralization of ZEBOV. Interestingly, all but one mouse (number 8) vaccinated with ZEBOVGP-Fc developed neutralizing antibodies (Fig. 4), and neutralization was antibody-dilution dependent. Mouse number 8 serum also showed low ELISA titers (Fig. 3A) and bound poorly to HEK293-ZEBOVGP cells as assessed by FACS analysis (Fig. 3B). Treatment with sera of mice vaccinated with FLAG-Fc did not neutralize rVSV-ZEBOVGP and resulted in background titer reductions of 40% or lower that were independent of the antibody dilution. These data show that all the mice vaccinated with ZEBOVGP-Fc except number 8 developed neutralizing antibodies against ZEBOV.

2.5. ZEBOVGP-Fc induces a $CD8^+$ T-cell response in vaccinated mice

[0101] Since protection against Filovirus infection is mediated by humoral and cellular immunity, we analyzed T-cell immunity in mice vaccinated with ZEBOVGP-Fc.

[0102] We used BALB/c mice to determine whether ZEBOVGP-Fc could also induced immunity in a different mouse strain. Groups of four BALB/c mice were vaccinated with ZEBOVGP-Fc or FLAG-Fc with the same protocol used for the C57BL/6 mice. The ZEBOVGP-Fc-vaccinated BALB/c mice also developed high titers of anti-ZEBOV GP Ab as assessed by the rVSV-ZEBOVGP viral particle ELISA (Fig. 5A) and neutralizing Ab as determined by the rVSV-ZEBOVGP plaque reduction assay (Fig. 5B). Eight days after the final immunization, mice were euthanized, spleens were harvested, and splenocytes were isolated and stimulated with ZEBOVGP-Fc or ZEBOV GP peptides. A significant increase in IFN-γ-positive $CD8^+$ cells was observed in splenocytes of ZEBOVGP-Fc-vaccinated mice stimulated with ZEBOVGP-Fc compared to FLAG-Fc (Fig. 6A-C). No increase in IFN-γ-positive $CD8^+$ cells was observed in splenocytes of FLAG-Fc-vaccinated mice stimulated with ZEBOVGP-Fc or FLAG-Fc. These data indicated that ZEBOVGP-Fc induced a significant increase in the level of anti-ZEBOV GP IFN-γ-positive $CD8^+$ cells. It should be pointed out that the Fc fragment was a weak inducer of IFN-γ-positive $CD8^+$ cells and resulted in a background level activation of T-cells from both ZEBOVGP-Fc and FLAG-Fc vaccinated mice. Unexpectedly, the ZEBOV GP specific peptides did not activate IFN-γ-positive $CD8^+$ cells in ZEBOVGP-Fc-vaccinated mice (Fig. 6D) compared to FLAG-Fc-vaccinated mice (Fig. 6E).

2.6. ZEBOVGP-Fc protect mice against ZEBOV challenge

[0103] Our results showed that ZEBOVGP-Fc elicited humoral and cellular immune responses in vaccinated mice. Therefore, we tested whether vaccination with ZEBOVGP-Fc could protect mice against a lethal ZEBOV challenge. C57BL/6 mice were vaccinated with ZEBOVGP-Fc or FLAG-Fc and challenged with 1,000 pfu of mouse-adapted ZEBOV seven weeks after the first vaccination (Fig. 7). Seven out of eight mice vaccinated with ZEBOVGP-Fc survived the ZEBOV challenge whereas seven out of the eight mice that received the FLAG-Fc vaccine died within 10 days after challenge. These data showed that EBOVGP-Fc elicited a protective immune response in mice against challenge with ZEBOV.

3. Discussion

[0104] The results presented here show that the GP ectodomain in the ZEBOVGP-Fc fusion protein underwent the complex posttranslational modification, including the furin cleavage and disulfide bond formation between the GP1 and GP2 subunits, of the membrane-bound full-length GP. Moreover, FPLC analysis of enterokinase-digested ZEBOVGP-Fc showed that the ZEBOVGP fragment of the Fc fusion protein formed trimers that resemble the natural GP expressed at the viral membrane and cell surface. Vaccination with ZEBOVGP-Fc elicited a humoral immune response that recognized membrane bound GP at the cell and viral particle surface. Interestingly, the anti-GP antibodies reacted similarly with inactivated ZEBOV and rVSV-ZEBOVGP, a replication-competent recombinant VSV particle carrying the ZEBOV GP at the viral surface that induces a protective response in non-human primates (NHP) (Feldmann et al., PLoS Pathog 2007 Jan;3(1):e2; Jones et al., Nat Med 2005 Jul;11(7):786-90). The anti-ZEBOVGP-Fc antibodies neutralized rVSV-ZEBOVGP indicating that this fusion protein also elicits protective neutralizing antibodies in NHP. These data show that rVSV-ZEBOVGP is a practical tool to evaluate total and neutralizing antibodies under BSL-2 conditions and indicate that recombinant VSV carrying the Filovirus GP can be used to assess vaccine potency, evaluate consistency in vaccine production, and as a surrogate marker of vaccine efficacy in clinical trials.

[0105] Cellular immunity characterized by the production of TNF-α and INF-γ plays a role in the protection against Filovirus infection (Hensley et al., PLoS Pathog 2010 May;6(5):e1000904 and references therein). ZEBOVGP-Fc induced a T-cell response in mice as evidenced by the activation of IFN-γ-positive $CD8^+$ cells in splenocytes stimulated with ZEBOVGP-Fc. Interestingly, stimulation with FLAG-Fc elicited a background level response indicating that the Fc fragment contributed minimally to the cellular response against the fusion protein. In NHP and humans, the human IgG1 Fc fragment present in ZEBOVGP-Fc is likely to be recognized as a self-antigen and may enhance the immunogenicity of the ZEBOVGP-Fc fusion protein by interacting with Fcγ receptors on antigen presenting cells (Zhang et al., Vaccine

2009 Feb 5;27(6):857-63; Guyre et al., Cancer Immunol Immunother 1997 Nov-Dec;45(3-4):146-8; Chen et al., Retrovirology 2007;4:33). It is not clear why the GP synthetic peptides were ineffective in activating GP-specific T-cells in ZEBOVGP-Fc vaccinated mice. In two studies, these peptides were shown to activate ZEBOV GP-specific T cells in mice under similar conditions used in our assay (Olinger *et al.,* and Warfield *et al., supra*). However, one of the peptides (LYDRLASTV) failed to activate IFN-γ-positive $CD8^+$ cells in BALB/c mice vaccinated with replication-deficient EbolaΔVP30 virus (Halfmann et al., J Virol 2009 Apr;83(8):3810). Further research will be required to determine whether ZEBOVGP-Fc vaccination elicited a cellular response against a different set of T-cell epitopes. Taken together, these results clearly show that ZEBOVGP-Fc induced both cellular and humoral immunity against the ZEBOV GP ectodomain.

[0106] One mouse vaccinated with ZEBOVGP-Fc did not survive the lethal challenge with ZEBOV. Unfortunately, we did not use individual identifiers at challenge and cannot unequivocally correlate the serology and the survival data. However, it is likely that the ZEBOVGP-Fc vaccinated animal that did not survive the challenge was the only mouse in the group that developed low levels of anti-ZEBOV GP antibodies that failed to neutralize rVSV-ZEBOVGP. Studies are being planned to determine whether the level of neutralizing antibodies against the replication-competent recombinant rVSV-ZEBOVGP correlates with protection against lethal challenge with ZEBOV.

[0107] These data indicate that ZEBOVGP-Fc can be used as a subunit Filovirus vaccine for human use. Previous attempts to develop Filovirus subunit vaccines based on soluble forms of Filovirus GP expressed in insect cells provided limited protection against lethal challenge in the guinea pig model (Mellquist-Riemenschneider et al., Virus Res 2003 Apr;92(2):187-9; Hevey et al., Virology 1997 Dec 8;239(1):206-16). It is possible that glycosylation in insect cells may have affected epitope structure, homotrimer formation, and stability of the soluble GP protein, factors that could account for the poor performance of the soluble GP vaccine. The ZEBOVGP-Fc used in this study was produced in mammalian cells and most likely resembles the native GP better than the soluble GP expressed in insect cells. In addition, the Fc tag in the ZEBOVGP-Fc conferred several advantages to our vaccine strategy including the ease of purification through protein A columns using mild conditions, an increased protein stability conferred by the Fc fragment, and the adjuvant effect due to the interactions with Fcγ receptors on antigen presenting cells (Zhang *et al.,* Guyre *et al.;* Chen *et al., supra*).

[0108] These results demonstrate that vaccination with the ZEBOVGP-Fc fusion protein elicited a high level of protection against challenge with ZEBOV and suggested that a subunit vaccine based on Filovirus GP-Fc fusion proteins could be developed to protect against viral infection. This Filovirus GP-Fc can be used as a stand-alone vaccine or in combination with other strategies such as DNA vaccines, virus-like particles, and viral vector vaccines that are currently under development. A subunit vaccine based on Filovirus GP-Fc fusion proteins is simple to produce, easy to purify, and cost-effective and will result in limited adverse events.

EXAMPLE 2

[0109] The immunogenicity of FiloGP-Fc was tested in guinea pigs and Rhesus monkeys with a construct containing the complete extracellular domain of the Zaire Ebola virus glycoprotein (ZEBOVGP) fused to the Fc fragment of human IgG1 (ZEBOVGP-Fc). Animals developed a strong anti-ZEBOVGP antibody response and sera neutralized Zaire Ebola virus pseudotypes. The methodology for the protein production, purification, determination of anti-ZEBOVGP antibodies by ELISA, and viral neutralization assays are as described in Example 1. The data presented here show that the FiloGP-Fc proteins are highly immunogenic in guinea pigs and Rhesus monkeys and elicit neutralizing antibodies that are found in the sera of convalescent patients that survived Filovirus infection.

Immunogenicity in Guinea Pigs.

[0110] Strain 13 guinea pigs were vaccinated with 0.1 mg of purified ZEBOVGP-Fc or Fc fragment in QS-21 adjuvant. Animals were boosted 2 times with the same dose of the corresponding vaccine at 3 weeks intervals. 2 weeks after the last boost, guinea pigs were bled and the collected sera were used for antibody analysis. Sera from all ZEBOVGP-Fc vaccinated animal contained high antibody titers against ZEBOVGP as assessed by virus particle ELISA (Figure 8), which ranged from 1/32,000 to 1/128,000. Control guinea pigs vaccinated with the Fc fragment alone (Figure 9) and pre-vaccination sera from all animals did not contain anti-ZEBOVGP antibodies indicating that the anti-ZEBOVGP antibody response was specific to the viral glycoprotein.

[0111] To analyze whether the anti-Ebola virus antibodies elicited by the ZEBOVGP-Fc vaccine could neutralize Ebola virus, sera from vaccinated animals (1:25 dilution) were incubated with ZEBOVGP pseudotype, and neutralization titers were assessed by an endpoint dilution neutralization assay in 96-well plates containing monolayers of Vero E6 cells. After 48 h incubation, wells were examined under the microscope for cytopathic effect due to virus infection. Percent neutralization was calculated compared to pre-immune sera treated virus (Figure 10). This neutralization assay clearly showed that vaccination with ZEBOVGP-Fc elicited anti-Ebola virus neutralizing antibodies whereas the Fc fragment alone did elicit neutralizing antibodies.

Immunogenicity in Rhesus monkeys.

[0112] Since the results in mice and guinea pigs clearly showed that ZEBOVGP-Fc was highly immunogenic and induced neutralizing anti-Ebola virus antibodies, the recombinant protein was tested to determine whether it could also elicit a strong immune response in Rhesus monkeys (Maccacamulata). To do so, we first determined whether the sera from Rhesus monkeys contained anti-Ebola virus antibodies. Virus particle ELISA revealed that sera from the three monkeys used in our studies did not contain anti-Ebola virus antibodies (Figure 11).

[0113] We then vaccinated two monkeys with 0.4 mg of purified ZEBOVGP-Fc and one monkey control with 0.4 mg of Fc fragment alone using poly(IC) as adjuvant. Three weeks after the primary immunization, the monkeys were bled and then boosted once with the same dose of the corresponding vaccine. Three weeks after the boost, monkeys were bled and sera samples were used for antibody analysis. Sera from the ZEBOVGP-Fc vaccinated animals contained high antibody titers against ZEBOVGP of approximately 1/32,000 as assessed by virus particle ELISA (Figure 12). As expected, the control monkey vaccinated with the Fc fragment alone did not develop anti-ZEBOVGP antibodies indicating that the anti-ZEBOVGP antibody response was specific for the viral glycoprotein.

[0114] To determine whether the monkeys inoculated with the ZEBOVGP-Fc vaccine developed anti-Ebola virus neutralizing antibodies, sera from the vaccinated animals (1:50 dilution) were incubated with ZEBOVGP pseudotype and neutralization titers were assessed by an endpoint dilution neutralization assay in 96-well plates containing monolayers of Vero E6 cells. After 48 h incubation, the 96-well plates were examined under the microscope for cytopathic effect due to the virus infection. Percent neutralization was calculated compared to pre-immune sera treated virus (Figure 13).

CONCLUSIONS

[0115] The data presented here clearly show that the ZEBOVGP-Fc vaccine induced high anti-Ebola virus neutralization titers in guinea pigs and monkeys. Moreover, this vaccine elicited anti-Filovirus neutralizing antibodies that can protect against Filovirus infection.

SEQUENCE LISTING

[0116]

SEQ ID NO:1 **ZEBOVgp-Fc nucleotide sequence**

ZEBOV GP translation initiation site

Synthetic splicing donor site to increase yield of Fc fusion protein

gtcgac SalI DNA restriction Site

actagt SpeI DNA restriction site

IgG1 Fc fragment gene DNA sequence containing introns and exons is underlined

gtcgacagt atg ggcgttacaggaatattgcagttacctcgtgatcgattcaagaggacatcattctttctttgggt
aattatccttttccaaagaacattttccatcccacttggagtcatccacaatagcacattacaggttagtgatgtcg
acaaactagtttgtcgtgacaaactgtcatccacaaatcaattgagatcagttggactgaatctcgaagggaatgga
gtggcaactgacgtgccatctgcaactaaaagatggggcttcaggtccggtgtcccaccaaaggtggtcaattatga
agctggtgaatgggctgaaaactgctacaatcttgaaatcaaaaaacctgacgggagtgagtgtctaccagcagcgc
cagacgggattcggggcttcccccggtgccggtatgtgcacaaagtatcaggaacgggaccgtgtgccggagacttt
gccttccataaagagggtgctttcttcctgtatgatcgacttgcttccacagttatctaccgaggaacgactttcgc
tgaaggtgtcgttgcatttctgatactgccccaagctaagaaggacttcttcagctcacacccctgagagagccgg
tcaatgcaacggaggacccgtctagtggctactattctaccacaattagatatcaggctaccggttttggaaccaat
gagacagagtacttgttcgaggttgacaatttgacctacgtccaacttgaatcaagattcacaccacagtttctgct
ccagctgaatgagacaatatatacaagtgggaaaaggagcaataccacgggaaaactaatttggaaggtcaaccccg
aaattgatacaacaatcggggagtgggccttctgggaaactaaaaaaaacctcactagaaaaattcgcagtgaagag
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gaccaacacaacaactgaagaccacaaaatcatggcttcagaaaattcctctgcaatggttcaagtgcacagtcaag
gaagggaagctgcagtgtcgcatctaacaacccttgccacaatctccacgagtccccaatccctcacaaccaaacca
ggtccggacaacagcacccataatacacccgtgtataaacttgacatctctgaggcaactcaagttgaacaacatca
ccgcagaacagacaacgacagcacagcctccgacactccctctgccacgaccgcagccggacccccaaaagcagaga
acaccaacacgagcaagagcactgacttcctggaccccgccaccacaacaagtccccaaaaccacagcgagaccgct
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gcaaccctaatttacattactggactactcaggatgaaggtgctgcaatcggactggcctggataccatatttcggg
ccagcagccgagggaatttacatagaggggctaatgcacaatcaagatggtttaatctgtgggttgagacagctggc
caacgagacgactcaagctcttcaactgttcctgagagccacaactgagctacgcacctttcaatcctcaaccgta
aggcaattgatttcttgctgcagcgatggggcggcacatgccacattctgggaccggactgctgtatcgaaccacat
gattggaccaagaacataacagacaaaattgatcagattattcatgattttgttgataaaaccccttccggacggtga
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tcttcacccggaggcctctgcccgccccactcatgctcagggagagggtcttctggctttttccccaggctctgggc
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tatccgggaggaccctgcccctgacctaagcccaccccaaaggccaaactctccactccctcagctcggacaccttc
tctcctcccagattccagtaactcccaatcttctctctgcagagcccaaatcttgtgacaaaactcacacatgccca
ccgtgcccaggtaagccagcccaggcctcgccctccagctcaaggcgggacaggtgccctagagtagcctgcatcca
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gtcttcctcttcccccaaaacccaaggacaccctcatgatctcccggaccccctgaggtcacatgcgtggtggtgga
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gacccgtggggtgcgagggccacatggacagaggccggctcggcccaccctctgccctgagagtgaccgctgtacca
acctctgtccctacagggcagccccgagaaccacaggtgtacaccctgccccatcccgggaggagatgaccaagaa
ccaggtcagcctgacctgcctggtcaaaggcttctatcccagcgacatcgccgtggagtgggagagcaatgggcagc
cggagaacaactacaagaccacgcctcccgtgctggactccgacggctccttcttcctctatagcaagctcaccgtg
gacaagagcaggtggcagcaggggaacgtcttctcatgctccgtgatgcatgaggctctgcacaaccactacacgca
gaagagcctctccctgtccccgggtaaatccagctcacaattgtctagatga

SEQ ID NO:2 ZEBOVgp-Fc protein
IgG1 Hinge
IgG1 Fc fragment is underlined

MGVTGILQLPRDRFKRTSFFLWVIILFQRTFSIPLGVIHNSTLQVSDVDKLVCRDKLSSTNQLR
SVGLNLEGNGVATDVPSATKRWGFRSGVPPKVVNYEAGEWAENCYNLEIKKPDGSECLPAAPDG
IRGFPRCRYVHKVSGTGPCAGDFAFHKEGAFFLYDRLASTVIYRGTTFAEGVVAFLILPQAKKD
FFSSHPLREPVNATEDPSSGYYSTTIRYQATGFGTNETEYLFEVDNLTYVQLESRFTPQFLLQL
NETIYTSGKRSNTTGKLIWKVNPEIDTTIGEWAFWETKKNLTRKIRSEELSFTVVSNGAKNISG
QSPARTSSDPGTNTTTEDHKIMASENSSAMVQVHSQGREAAVSHLTTLATISTSPQSLTTKPGP
DNSTHNTPVYKLDISEATQVEQHHRRTDNDSTASDTPSATTAAGPPKAENTNTSKSTDFLDPAT
TTSPQNHSETAGNNNTHHQDTGEESASSGKLGLITNTIAGVAGLITGGRRTRREAIVNAQPKCN
PNLHYWTTQDEGAAIGLAWIPYFGPAAEGIYIEGLMHNQDGLICGLRQLANETTQALQLFLRAT
TELRTFSILNRKAIDFLLQRWGGTCHILGPDCCIEPHDWTKNITDKIDQIIHDFVDKTLPDGTC
PPCPAPELLGGPSVFLFPPKPKDTLMISRTPEVTCVVVDVSHEDPEVKFNWYVDGVEVHNAKTK
PREEQYNSTYRVVSVLTVLHQDWLNGKEYKCKVSNKALPAPIEKTISKAKGQPREPQVYTLPPS
RDELTKNQVSLTCLVKGFYPSDIAVEWESNGQPENNYKTTPPVLDSDGPFFLYSKLTVDKSRWQ
QGNVFSCSVMHEALHNHYTQKSLSLSPGK

SEQ ID NO:3 **ZEBOVgpFLAG-Fc nucleotide sequence**

ZEBOV GP translation initiation site

Synthetic splicing donor site to increase yield of Fc fusion protein

gtcgac SalI DNA restriction Site

actagt SpeI DNA restriction site

gactacaaggacgacgatgacaag FLAG tag and enterokinase protease restriction site

Codons for glycine residues in capital letters were added to increase flexibility at both ends of the FLAG tag

IgG1 Fc fragment gene DNA sequence containing introns and exons is underlined

gtcgacagtatggcgttacaggaatattgcagttacctcgtgatcgattcaagaggacatcattctttctttgggt
aattatccttttccaaagaacattttccatcccacttggagtcatccacaatagcacattacaggttagtgatgtcg
acaaactagtttgtcgtgacaaactgtcatccacaaatcaattgagatcagttggactgaatctcgaagggaatgga
gtggcaactgacgtgccatctgcaactaaaagatggggcttcaggtccggtgtcccaccaaaggtggtcaattatga
agctggtgaatgggctgaaaactgctacaatcttgaaatcaaaaaacctgacgggagtgagtgtctaccagcagcgc
agacgggattcggggcttcccccggtgccggtatgtgcacaaagtatcaggaacgggaccgtgtgccggagactttg
ccttccataaagagggtgctttcttcctgtatgatcgacttgcttccacagttatctaccgaggaacgactttcgct
gaaggtgtcgttgcatttctgatactgccccaagctaagaaggacttcttcagctcacacccccttgagagagccggt
caatgcaacggaggacccgtctagtggctactattctaccacaattagatatcaggctaccggttttggaaccaatg
agacagagtacttgttcgaggttgacaatttgacctacgtccaacttgaatcaagattcacaccacagtttctgctc
cagctgaatgagacaatatatacaagtgggaaaaggagcaataccacgggaaaactaatttggaaggtcaaccccga
aattgatacaacaatcggggagtgggccttctgggaaactaaaaaaaacctcactagaaaaattcgcagtgaagagt
tgtctttcacagttgtatcaaacggagccaaaaacatcagtggtcagagtccggcgcgaacttcttccgacccaggg
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aagggaagctgcagtgtcgcatctaacaacccttgccacaatctccacgagtccccaatccctcacaaccaaaccag
gtccggacaacagcacccataatacacccgtgtataaacttgacatctctgaggcaactcaagttgaacaacatcac
cgcagaacagacaacgacagcacagcctccgacactccctctgccacgaccgcagccggacccccaaaagcagagaa
caccaacacgagcaagagcactgacttcctggaccccgccaccacaacaagtccccaaaaccacagcgagaccgctg
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accctgcccccatcccgggaggagatgaccaagaaccaggtcagcctgacctgcctggtcaaaggcttctatcccag
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acggctccttcttcctctatagcaagctcaccgtggacaagagcaggtggcagcaggggaacgtcttctcatgctcc
gtgatgcatgaggctctgcacaaccactacacgcagaagagcctctccctgtccccgggtaaatccagctcacaatt
gtctagatga

SEQ ID NO:4 ZEBOVgpFLAG-Fc protein
IgG1 Hinge
IgG1 Fc fragment is underlined
FLAG tag is in Bold characters

MGVTGILQLPRDRFKRTSFFLWVIILFQRTFSIPLGVIHNSTLQVSDVDKLVCRDKLSSTNQLR
SVGLNLEGNGVATDVPSATKRWGFRSGVPPKVVNYEAGEWAENCYNLEIKKPDGSECLPAAPDG
IRGFPRCRYVHKVSGTGPCAGDFAFHKEGAFFLYDRLASTVIYRGTTFAEGVVAFLILPQAKKD
FFSSHPLREPVNATEDPSSGYYSTTIRYQATGFGTNETEYLFEVDNLTYVQLESRFTPQFLLQL
NETIYTSGKRSNTTGKLIWKVNPEIDTTIGEWAFWETKKNLTRKIRSEELSFTVVSNGAKNISG
QSPARTSSDPGTNTTTEDHKIMASENSSAMVQVHSQGREAAVSHLTTLATISTSPQSLTTKPGP
DNSTHNTPVYKLDISEATQVEQHHRRTDNDSTASDTPSATTAAGPPKAENTNTSKSTDFLDPAT
TTSPQNHSETAGNNNTHHQDTGEESASSGKLGLITNTIAGVAGLITGGRRTRREAIVNAQPKCN
PNLHYWTTQDEGAAIGLAWIPYFGPAAEGIYIEGLMHNQDGLICGLRQLANETTQALQLFLRAT
TELRTFSILNRKAIDFLLQRWGGTCHILGPDCCIEPHDWTKNITDKIDQIIHDFVDKTLPD**DYK**
DDDDKGGTCPPCPAPELLGGPSVFLFPPKPKDTLMISRTPEVTCVVVDVSHEDPEVKFNWYVDG
VEVHNAKTKPREEQYNSTYRVVSVLTVLHQDWLNGKEYKCKVSNKALPAPIEKTISKAKGQPRE
PQVYTLPPSRDELTKNQVSLTCLVKGFYPSDIAVEWESNGQPENNYKTTPPVLDSDGPFFLYSK
LTVDKSRWQQGNVFSCSVMHEALHNHYTQKSLSLSPGK

Claims

1. A fusion protein comprising a Filovirus glycoprotein segment comprising the extracellular domain and an immunoglobulin polypeptide segment comprising an Fc fragment of an immunoglobulin heavy chain constant domain polypeptide, wherein the C-terminus of the Filovirus glycoprotein segment is attached to the N-terminus of the

immunoglobulin polypeptide segment.

2. The fusion protein of claim 1, wherein the immunoglobulin is IgG1.

3. The fusion protein of claim 1, wherein the Filovirus glycoprotein segment is from an Ebola virus, optionally a Zaire Ebola virus, Mayinga strain.

4. The fusion protein of claim 1, further comprising a linker between the Filovirus glycoprotein segment and the immunoglobulin polypeptide segment.

5. The fusion protein of claim 1, which has the sequence as shown in SEQ ID NO: 2.

6. A nucleic acid vector comprising a nucleic acid sequence encoding the fusion protein of any one of claims 1 to 5.

7. The nucleic acid vector of claim 6, wherein the nucleic acid sequence encoding the fusion protein has the sequence as shown in SEQ ID NO: 1.

8. An immunogenic composition comprising the fusion protein of claim 1 or the nucleic acid vector of claim 6, wherein the immunogenic composition optionally comprises an adjuvant.

9. The composition of claim 8 for use in a method of inducing a protective immune response against Filovirus infection in a patient.

10. The composition for use in a method of claim 9, wherein the immunogenic composition is formulated for intramuscular administration.

11. The composition for use in a method of claim 9, wherein the method further comprises inducing a protective immune response against a second Filovirus antigen.

12. A method of detecting an immune response against Filovirus in a patient, the method comprising contacting a biological sample from the patient with the fusion protein of claim 1 and detecting an immune response.

13. The method of claim 12, wherein the step of detecting an immune response includes the step of detecting binding of antibodies in the biological sample to the fusion protein, wherein the step of detecting binding of antibodies is optionally carried by ELISA, a chemiluminescence assay, or a fluorescence assay.

14. The method of claim 12, wherein the step of detecting an immune response includes the step of detecting a cellular immune response, wherein the step of detecting the cellular immune response is optionally carried by detecting IFN-γ or TNF-α.

Patentansprüche

1. Fusionsprotein, umfassend ein Filovirus-Glycoprotein-Segment, das die extrazelluläre Domäne umfasst, und ein Immunglobulin-Polypeptid-Segment, das ein Fc-Fragment eines Polypeptids einer konstanten Domäne der schweren Immunglobulinkette umfasst, wobei der C-Terminus des Filovirus-Glycoprotein-Segments an den N-Terminus des Immunglobulin-Polypeptid-Segments angebunden ist.

2. Fusionsprotein nach Anspruch 1, wobei das Immunglobulin IgG1 ist.

3. Fusionsprotein nach Anspruch 1, wobei das Filovirus-Glycoprotein-Segment von einem Ebola-Virus ist, wahlweise einem Zaire-Ebola-Virus, Mayinga-Stamm.

4. Fusionsprotein nach Anspruch 1, ferner umfassend einen Linker zwischen dem Filovirus-Glycoprotein-Segment und dem Immunglobulin-Polypeptid-Segment.

5. Fusionsprotein nach Anspruch 1, das die Sequenz wie in SEQ ID NO: 2 gezeigt hat.

6. Nukleinsäurevektor, der eine Nukleinsäuresequenz umfasst, die für das Fusionsprotein nach einem der Ansprüche 1 bis 5 kodiert.

7. Nukleinsäurevektor nach Anspruch 6, wobei die Nukleinsäuresequenz, die für das Fusionsprotein kodiert, die Sequenz hat wie gezeigt in SEQ ID NO: 1.

8. Immunogene Zusammensetzung, umfassend das Fusionsprotein nach Anspruch 1 oder den Nukleinsäurevektor nach Anspruch 6, wobei die immunogene Zusammensetzung wahlweise ein Adjuvans umfasst.

9. Zusammensetzung nach Anspruch 8 zur Verwendung in einem Verfahren zum Induzieren einer schützenden Immunantwort gegen eine Filovirus-Infektion in einem Patienten.

10. Zusammensetzung zur Verwendung in einem Verfahren nach Anspruch 9, wobei die immunogene Zusammensetzung für eine intramuskuläre Verabreichung formuliert ist.

11. Zusammensetzung zur Verwendung in einem Verfahren nach Anspruch 9, wobei das Verfahren ferner das Induzieren einer schützenden Immunantwort gegen ein zweites Filovirus-Antigen umfasst.

12. Verfahren zum Nachweisen einer Immunantwort gegen Filovirus in einem Patienten, wobei das Verfahren das Inkontaktbringen einer biologischen Probe des Patienten mit dem Fusionsprotein nach Anspruch 1 und das Nachweisen einer Immunantwort umfasst.

13. Verfahren nach Anspruch 12, wobei der Schritt des Nachweisens einer Immunantwort den Schritt des Nachweisens der Bindung von Antikörpern in der biologischen Probe an das Fusionsprotein umfasst, wobei der Schritt des Nachweisens der Bindung von Antikörpern wahlweise durch ELISA, einen Chemolumineszenzassay oder einen Fluoreszenzassay erfolgt.

14. Verfahren nach Anspruch 12, wobei der Schritt des Nachweisens einer Immunantwort den Schritt des Nachweisens einer zellulären Immunantwort umfasst, wobei der Schritt des Nachweisens der zellulären Immunantwort wahlweise durch das Nachweisen von IFN- γ oder TNF-α erfolgt.

Revendications

1. Protéine de fusion comprenant un segment de glycoprotéine de filovirus comprenant le domaine extracellulaire et un segment de polypeptide d'immunoglobuline comprenant un fragment de Fc d'un polypeptide de domaine constant de chaîne lourde d'immunoglobuline, la terminaison C du segment de glycoprotéine de filovirus étant lié à la terminaison N du segment de polypeptide d'immunoglobuline.

2. Protéine de fusion selon la revendication 1, dans lequel l'immunoglobuline est IgG1.

3. Protéine de fusion selon la revendication 1, dans lequel le segment de glycoprotéine de filovirus provient d'un virus Ebola, éventuellement un virus Ebola du Zaïre, souche de Mayinga.

4. Protéine de fusion selon la revendication 1, comprenant en outre un lieur entre le segment de glycoprotéine de filovirus et le segment de polypeptide d'immunoglobuline.

5. Protéine de fusion selon la revendication 1, qui présente la séquence telle qu'indiquée dans la SEQ ID n° : 2.

6. Vecteur d'acide nucléique comprenant une séquence d'acide nucléique codant pour la protéine de fusion selon l'une quelconque des revendications 1 à 5.

7. Vecteur d'acide nucléique selon la revendication 6, dans lequel la séquence d'acide nucléique codant pour la protéine de fusion présente la séquence telle qu'indiquée dans la SEQ ID n° : 1.

8. Composition immunogène comprenant la protéine de fusion selon la revendication 1 ou vecteur d'acide nucléique selon la revendication 6, la composition immunogène comprenant éventuellement un adjuvant.

9. Composition selon la revendication 8, destinée à une utilisation dans une méthode d'induction d'une réponse immunitaire protectrice contre l'infection au filovirus chez un patient.

10. Composition destinée à une utilisation dans une méthode selon la revendication 9, la composition immunogène étant formulée pour une administration intramusculaire.

11. Composition destinée à une utilisation dans une méthode selon la revendication 9, la méthode comprenant en outre l'induction d'une réponse immunitaire protectrice contre un deuxième antigène de filovirus.

12. Procédé de détection d'une réponse immunitaire contre le filovirus chez un patient, le procédé comprenant la mise en contact d'un échantillon biologique provenant du patient avec la protéine de fusion selon la revendication 1 et la détection d'une réponse immunitaire.

13. Procédé selon la revendication 12, dans lequel l'étape de détection d'une réponse immunitaire comprend l'étape de détection d'une liaison d'anticorps dans l'échantillon biologique à la protéine de fusion, l'étape de détection de la liaison d'anticorps étant éventuellement effectuée par ELISA, une analyse par chimioluminescence ou une analyse par fluorescence.

14. Procédé selon la revendication 12, dans lequel l'étape de détection d'une réponse immunitaire comprend l'étape de détection d'une réponse immunitaire cellulaire, l'étape de détection de la réponse immunitaire cellulaire étant éventuellement effectuée par la détection d'IFN-γ ou de TNF-α.

FIGURE 1

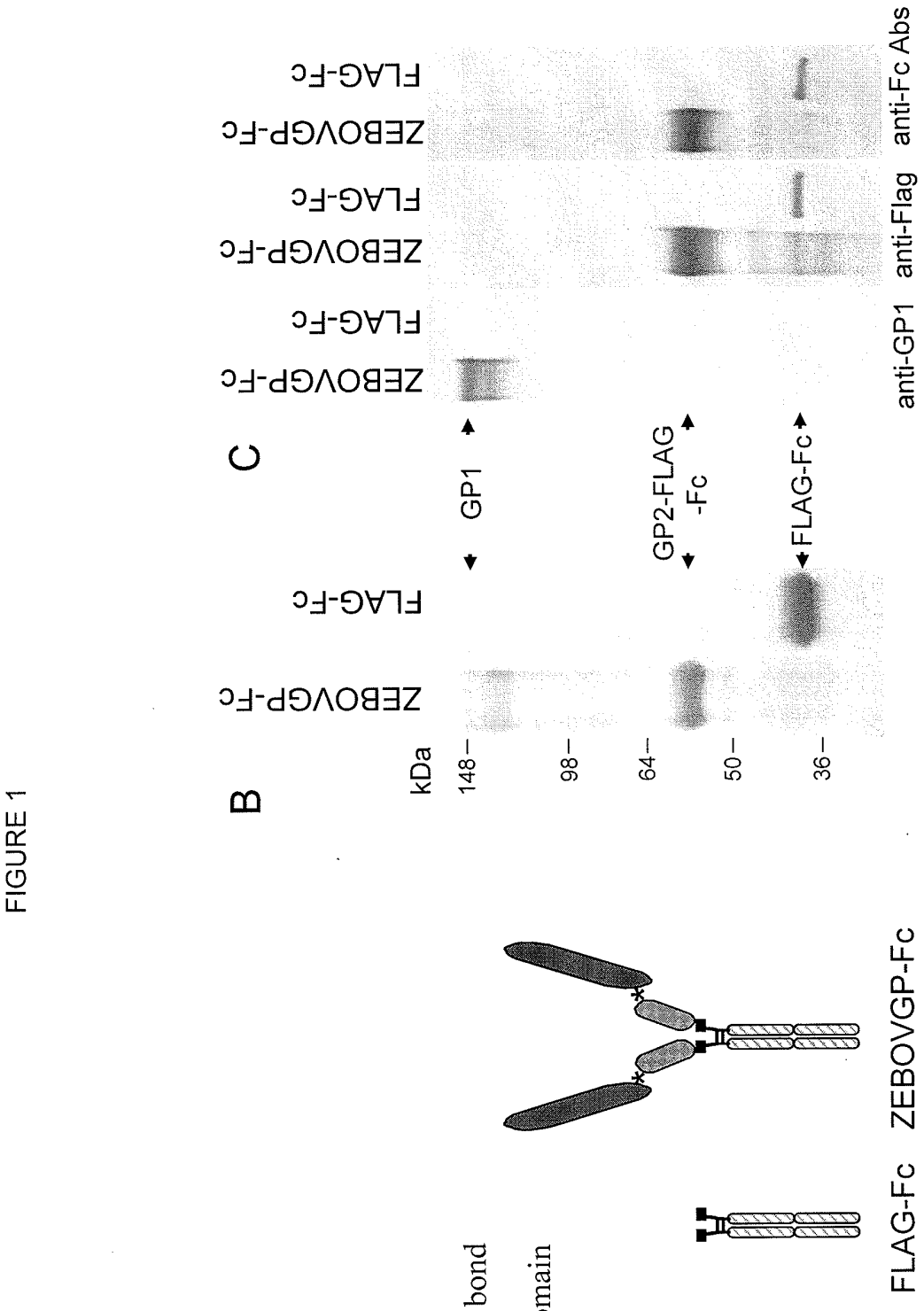

A
GP1
* Disulphide bond
GP2 ectodomain
■ FLAG
IgG1 Fc
FLAG-Fc
ZEBOVGP-Fc
B
kDa
148
98
64
50
36
ZEBOVGP-Fc
FLAG-Fc
C
GP1
GP2-FLAG -Fc
FLAG-Fc
ZEBOVGP-Fc
FLAG-Fc
ZEBOVGP-Fc
FLAG-Fc
anti-GP1
anti-Flag
anti-Fc Abs

FIGURE 2A

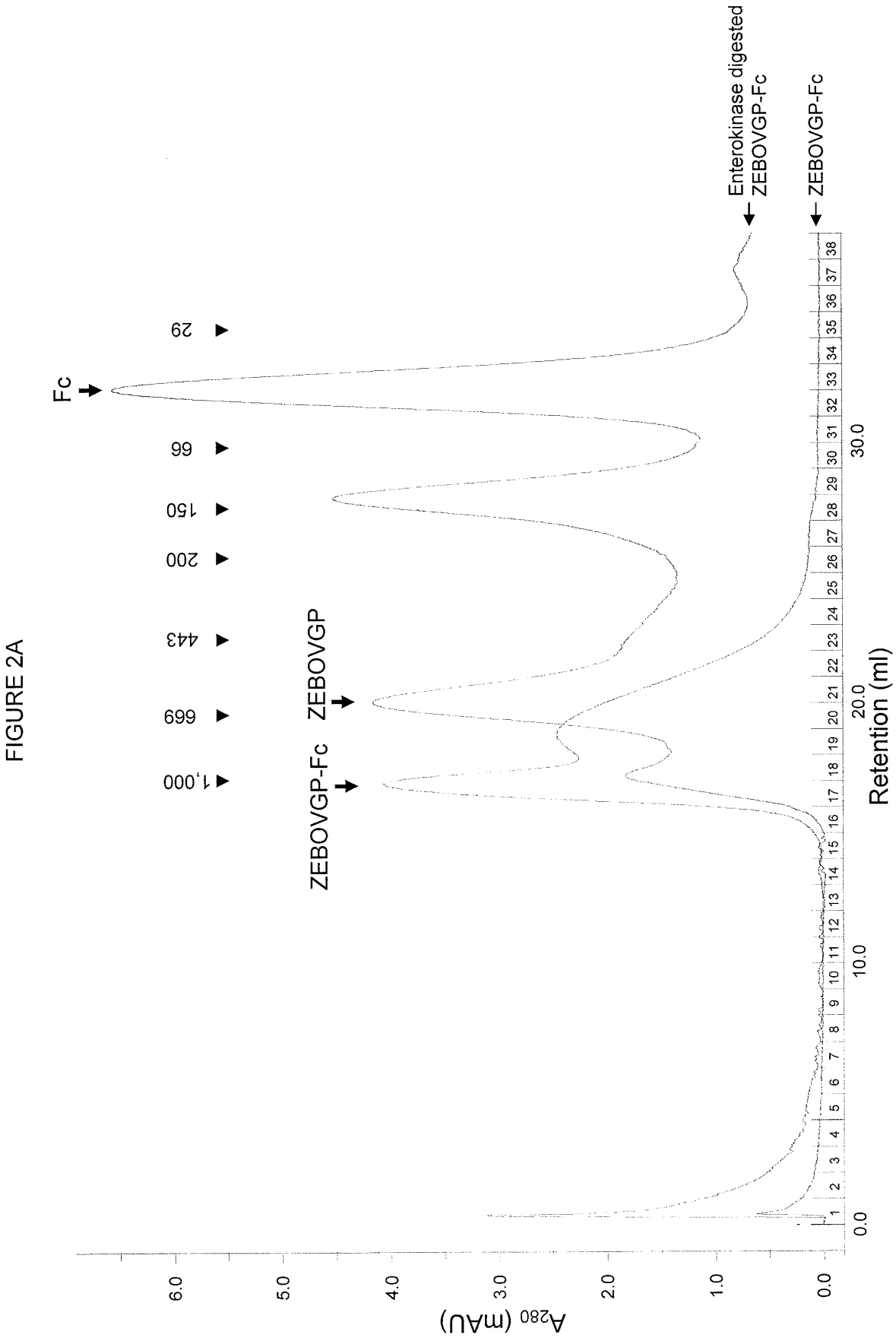

Enterokinase digested ZEBOVGP-Fc
ZEBOVGP-Fc
Fc
ZEBOVGP
ZEBOVGP-Fc
29
66
150
200
443
669
1,000
A_{280} (mAU)
Retention (ml)

FIGURE 2B

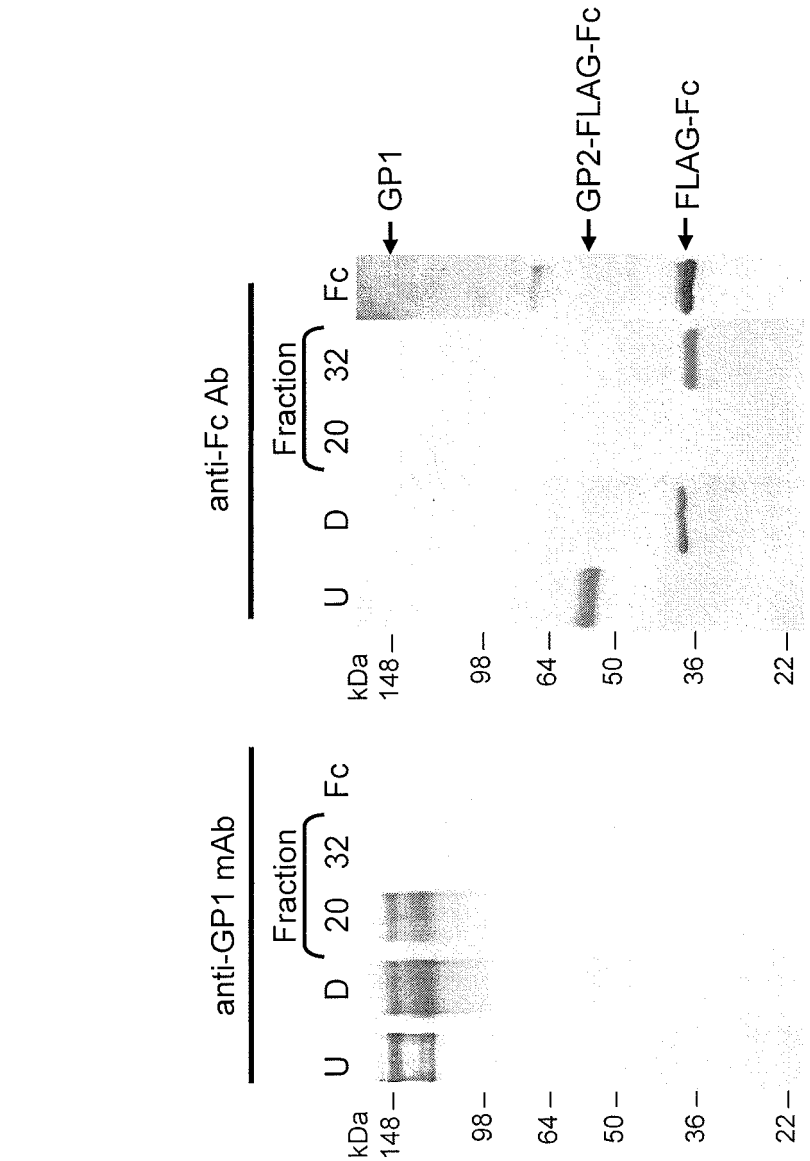

anti-GP1 mAb
anti-Fc Ab
U
D
Fraction
20
32
Fc
kDa
148
98
64
50
36
22
GP1
GP2-FLAG-Fc
FLAG-Fc

FIGURE 3A

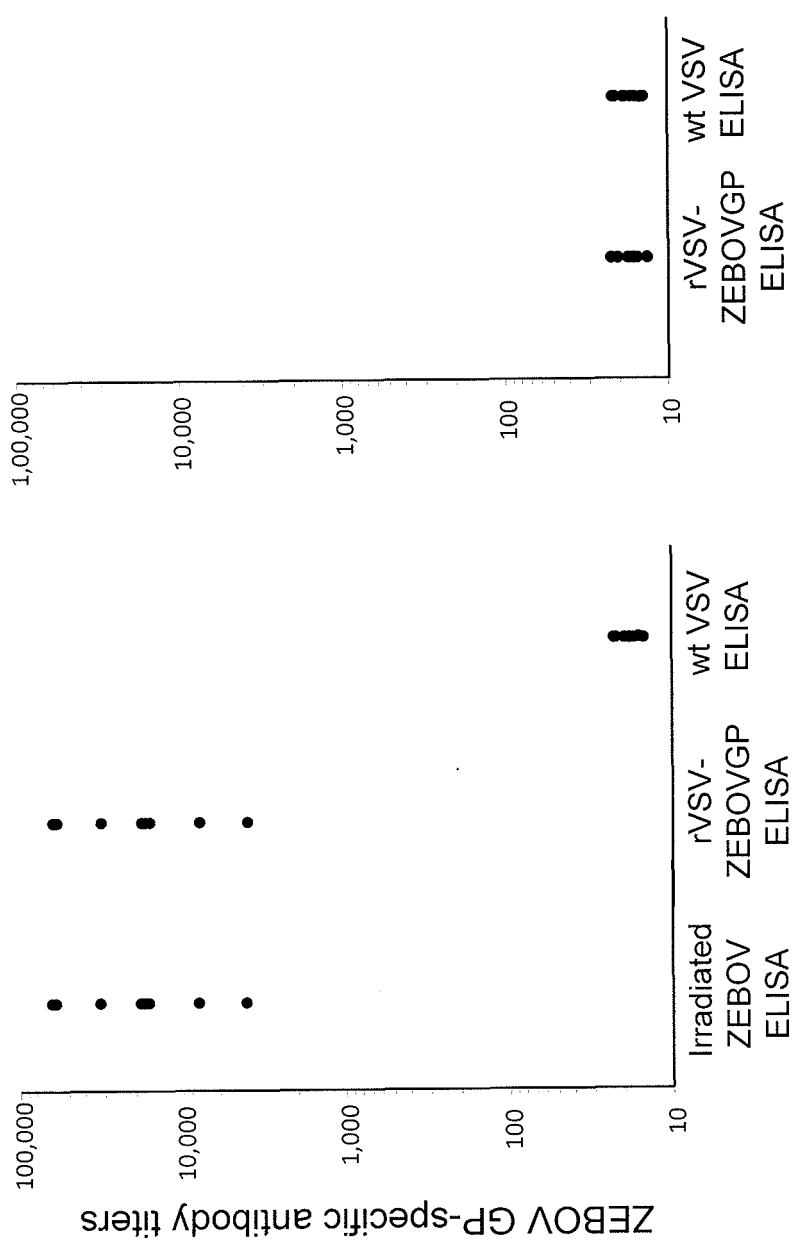

ZEBOVGP-Fc vaccinated mice
FLAG-Fc vaccinated mice
ZEBOV GP-specific antibody titers
100,000
10,000
1,000
100
10
1,00,000
10,000
1,000
100
10
Irradiated ZEBOV ELISA
rVSV-ZEBOVGP ELISA
wt VSV ELISA
rVSV-ZEBOVGP ELISA
wt VSV ELISA

FIGURE 3B

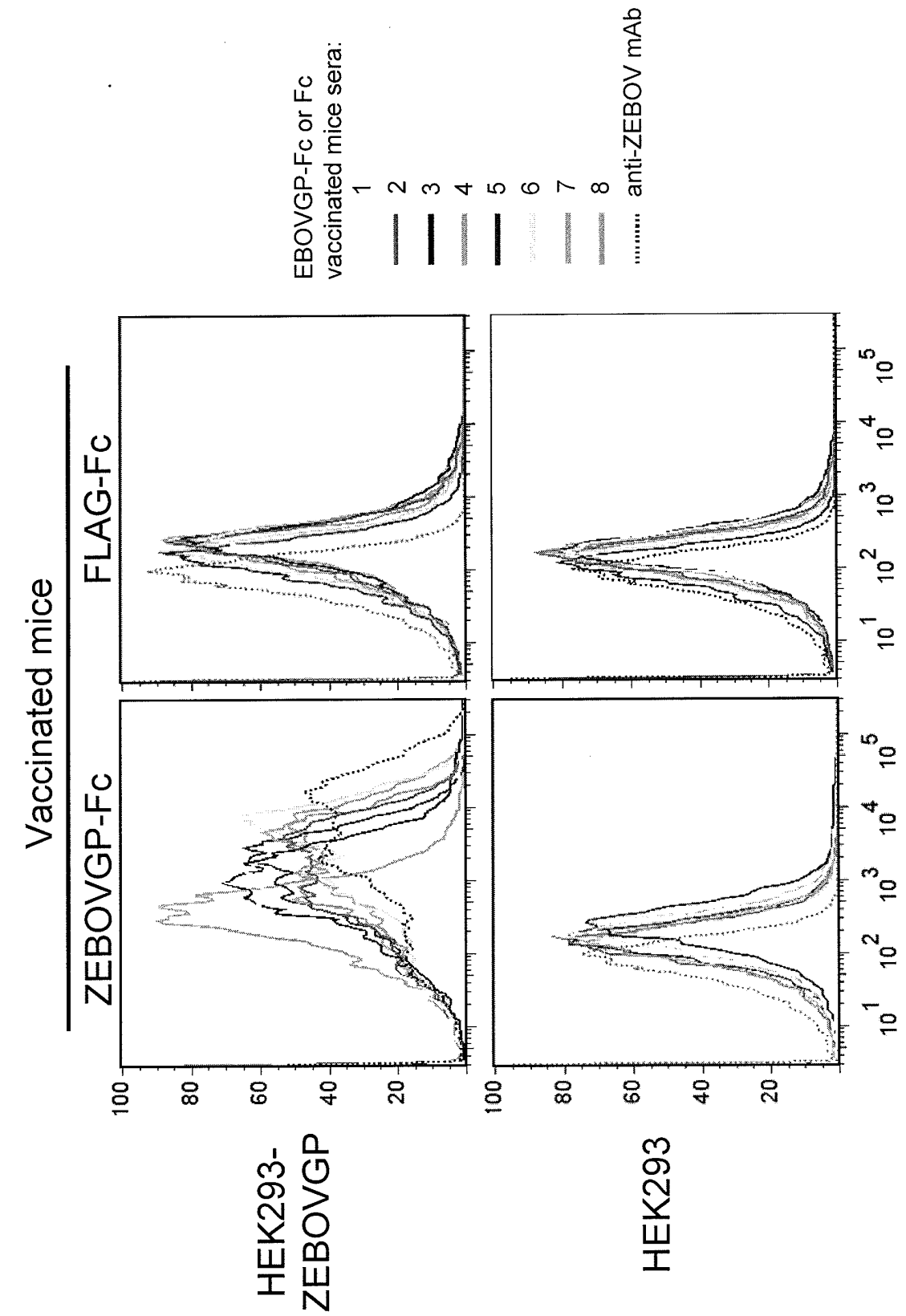

Vaccinated mice
ZEBOVGP-Fc
FLAG-Fc
HEK293-ZEBOVGP
HEK293
EBOVGP-Fc or Fc vaccinated mice sera:
1
2
3
4
5
6
7
8
anti-ZEBOV mAb
100
80
60
40
20
10^1
10^2
10^3
10^4
10^5

FIGURE 4

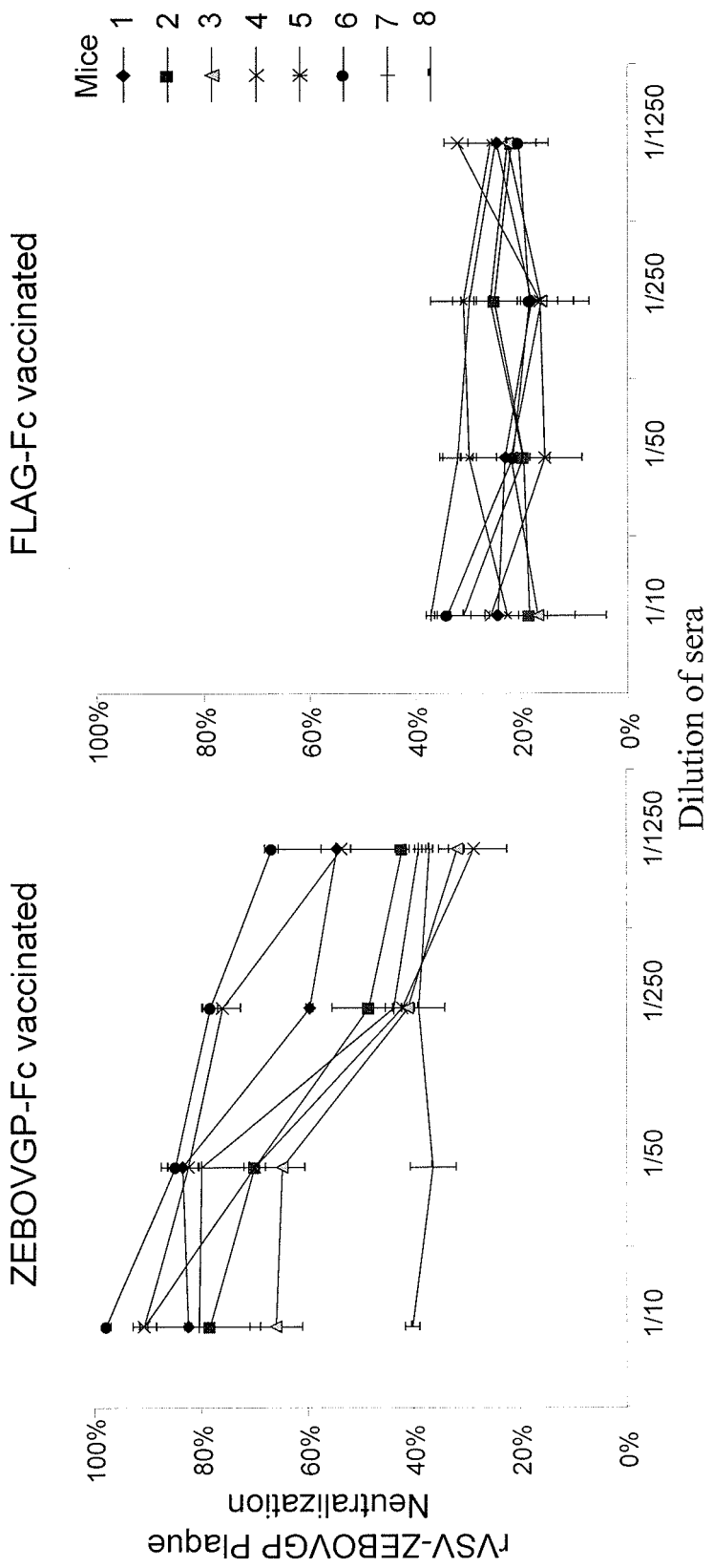

ZEBOVGP-Fc vaccinated
FLAG-Fc vaccinated
Mice
1
2
3
4
5
6
7
8
rVSV-ZEBOVGP Plaque Neutralization
100%
80%
60%
40%
20%
0%
1/10
1/50
1/250
1/1250
Dilution of sera

FIGURE 5

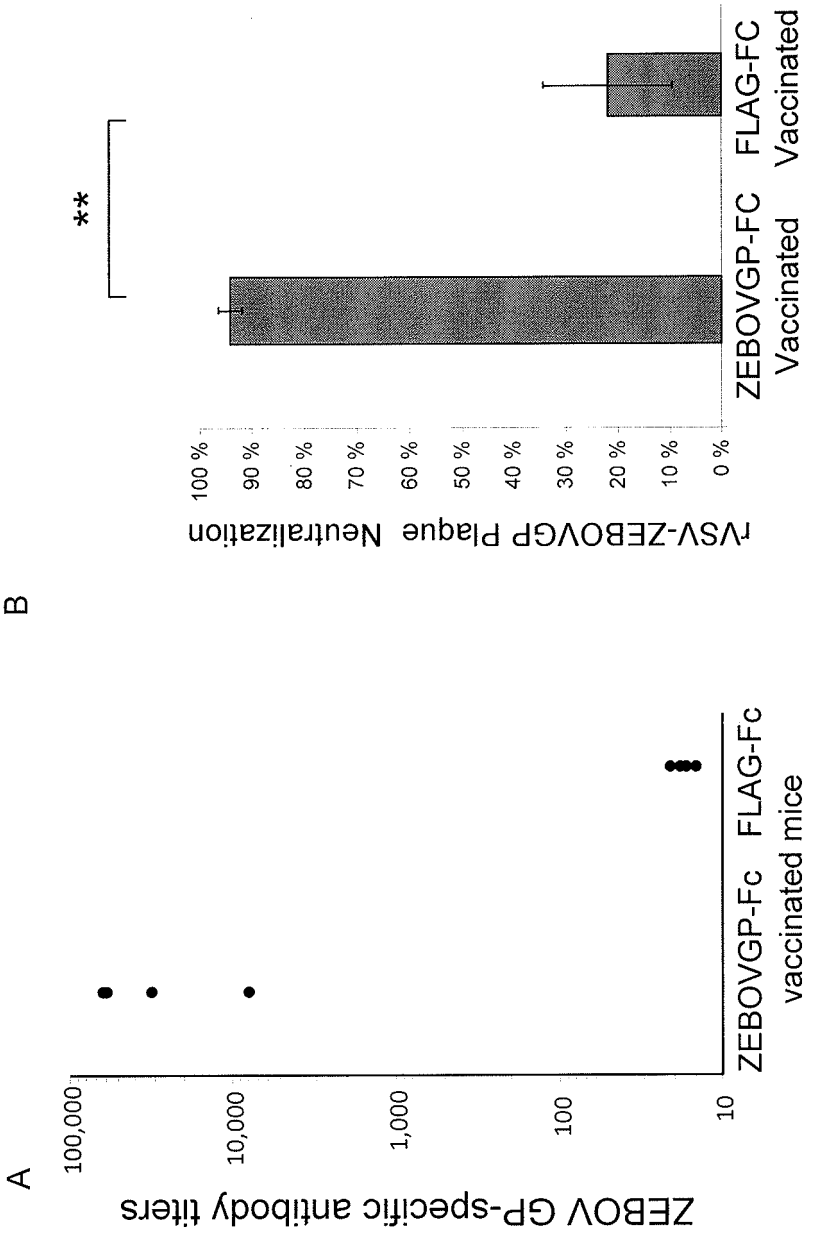

A
ZEBOV GP-specific antibody titers
100,000
10,000
1,000
100
10
ZEBOVGP-Fc
FLAG-Fc
vaccinated mice
B
rVSV-ZEBOVGP Plaque Neutralization
100 %
90 %
80 %
70 %
60 %
50 %
40 %
30 %
20 %
10 %
0 %
**
ZEBOVGP-FC
Vaccinated
FLAG-FC
Vaccinated

FIGURE 6A

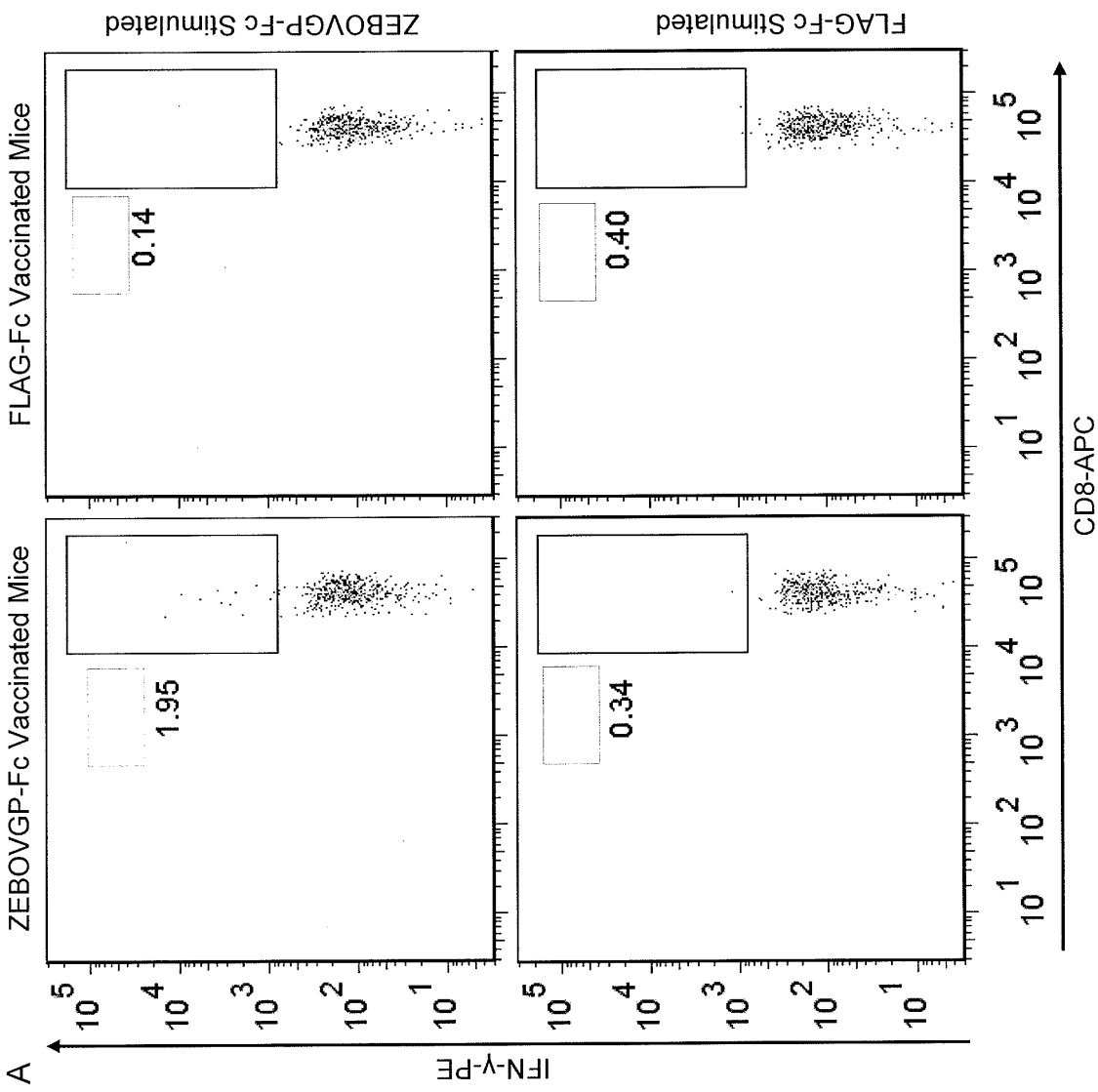

A
ZEBOVGP-Fc Vaccinated Mice
FLAG-Fc Vaccinated Mice
ZEBOVGP-Fc Stimulated
FLAG-Fc Stimulated
1.95
0.14
0.34
0.40
IFN-γ-PE
CD8-APC
10^1
10^2
10^3
10^4
10^5

FIGURE 6 B- FIGURE 6E

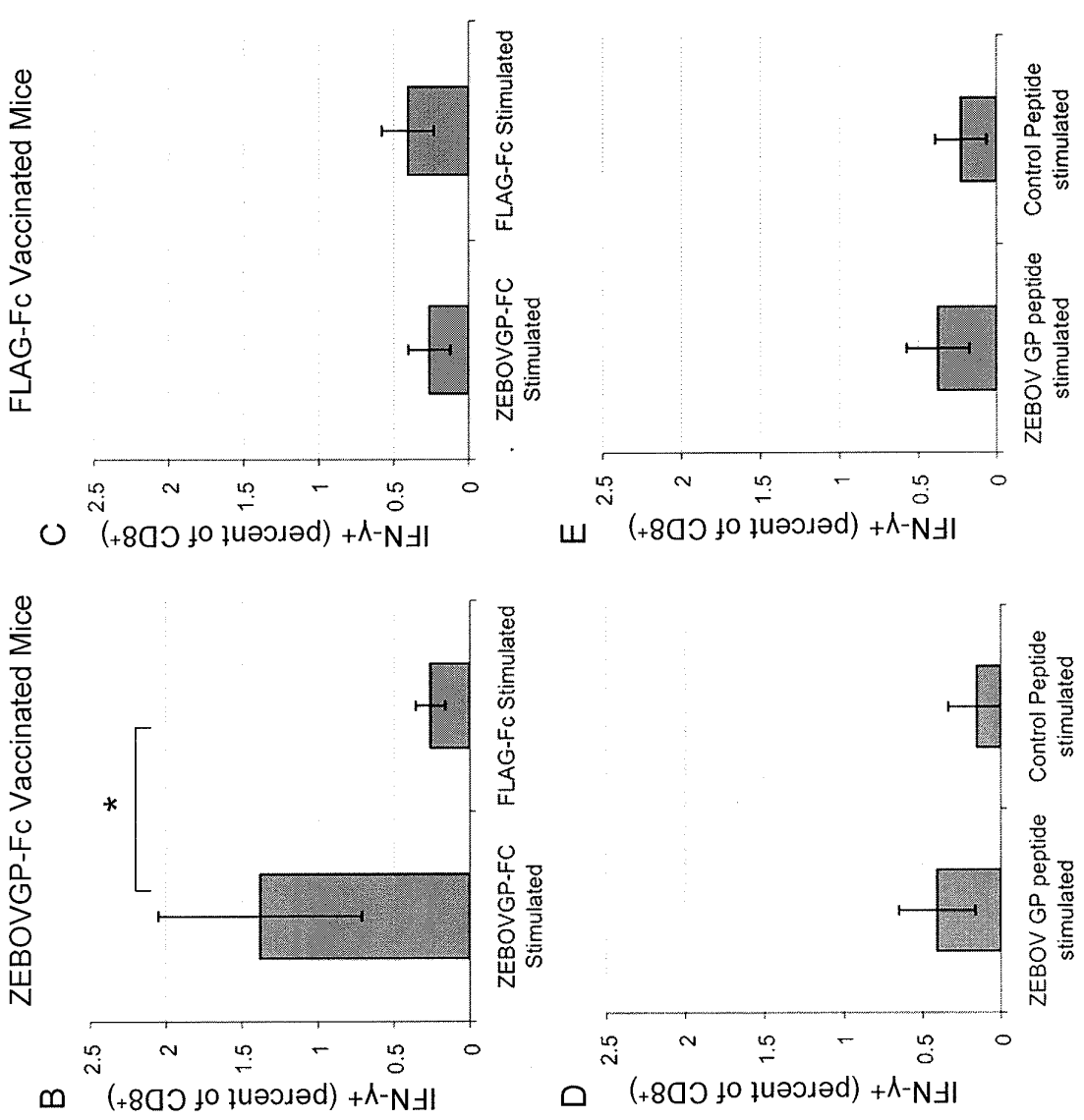


FIGURE 7

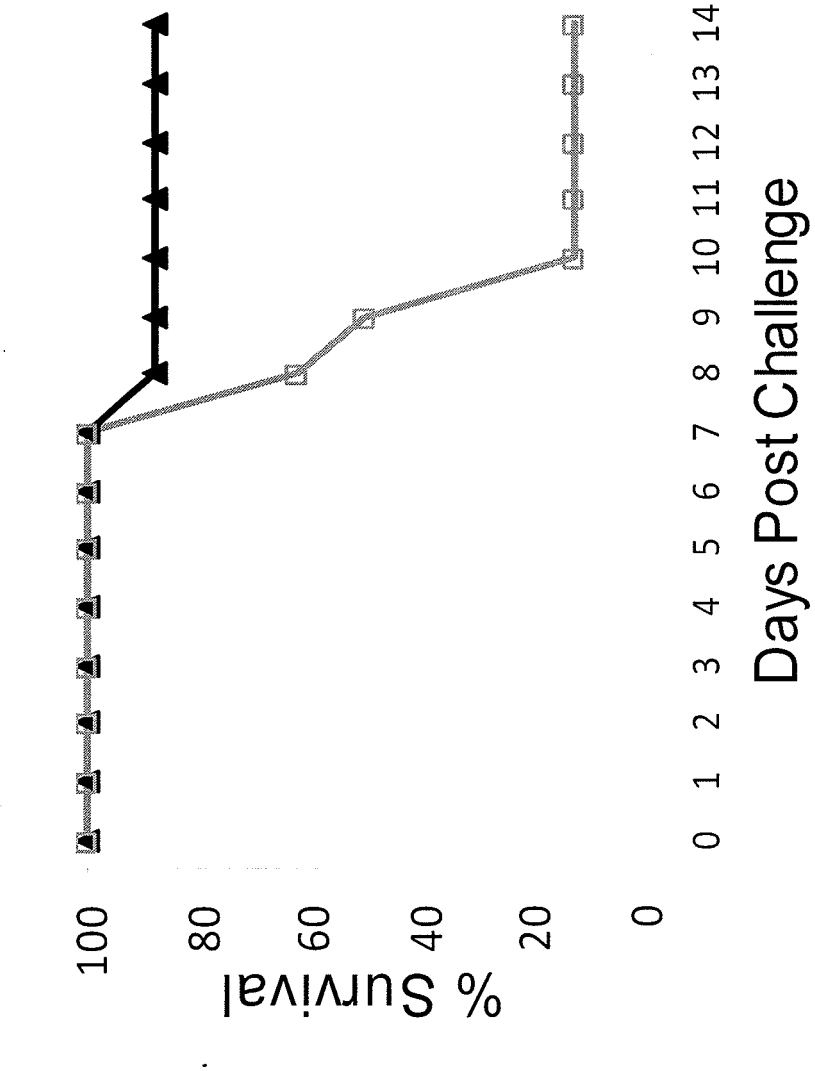

% Survival
100
80
60
40
20
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
Days Post Challenge

FIGURE 8

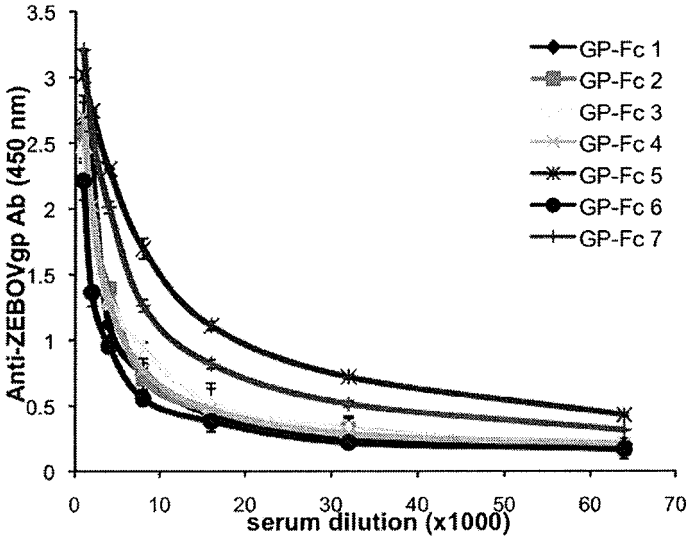

Anti-ZEBOVgp Ab (450 nm)
serum dilution (x1000)
GP-Fc 1
GP-Fc 2
GP-Fc 3
GP-Fc 4
GP-Fc 5
GP-Fc 6
GP-Fc 7
0
0.5
1
1.5
2
2.5
3
3.5
0
10
20
30
40
50
60
70

FIGURE 9

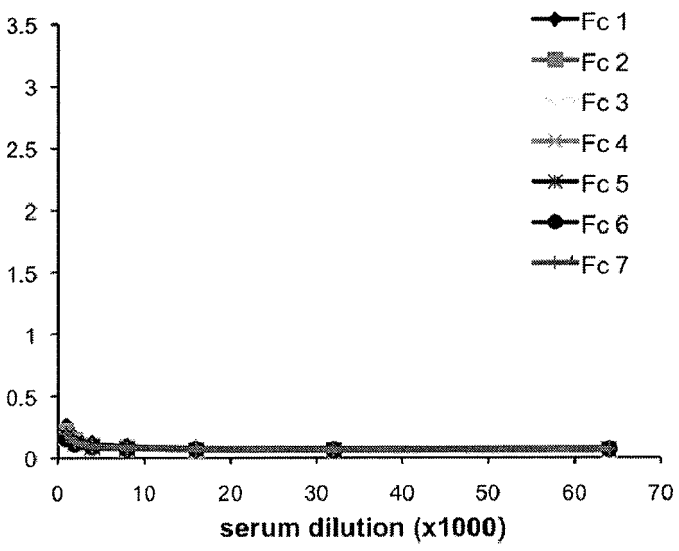

3.5
3
2.5
2
1.5
1
0.5
0
0
10
20
30
40
50
60
70
serum dilution (x1000)
Fc 1
Fc 2
Fc 3
Fc 4
Fc 5
Fc 6
Fc 7

FIGURE 10

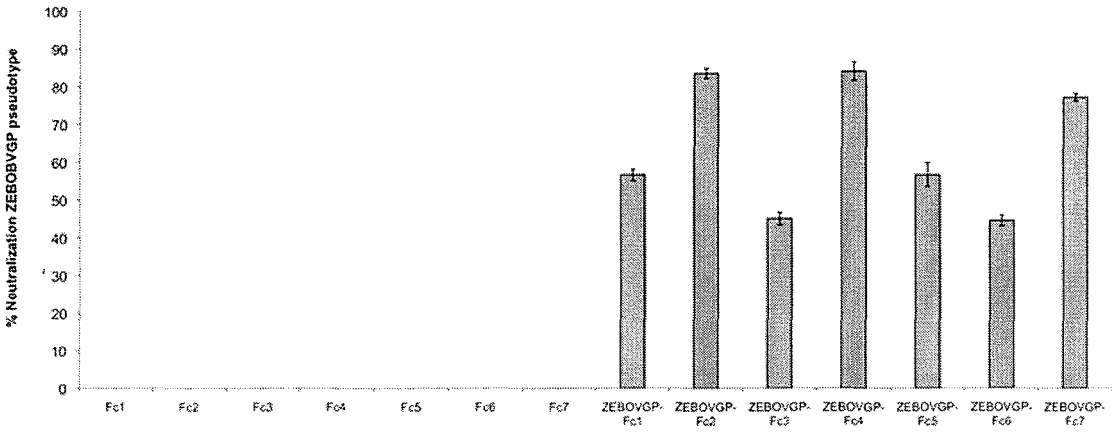

% Neutralization ZEBOBVGP pseudotype
100
90
80
70
60
50
40
30
20
10
0
Fc1
Fc2
Fc3
Fc4
Fc5
Fc6
Fc7
ZEBOVGP-Fc1
ZEBOVGP-Fc2
ZEBOVGP-Fc3
ZEBOVGP-Fc4
ZEBOVGP-Fc5
ZEBOVGP-Fc6
ZEBOVGP-Fc7

FIGURE 11

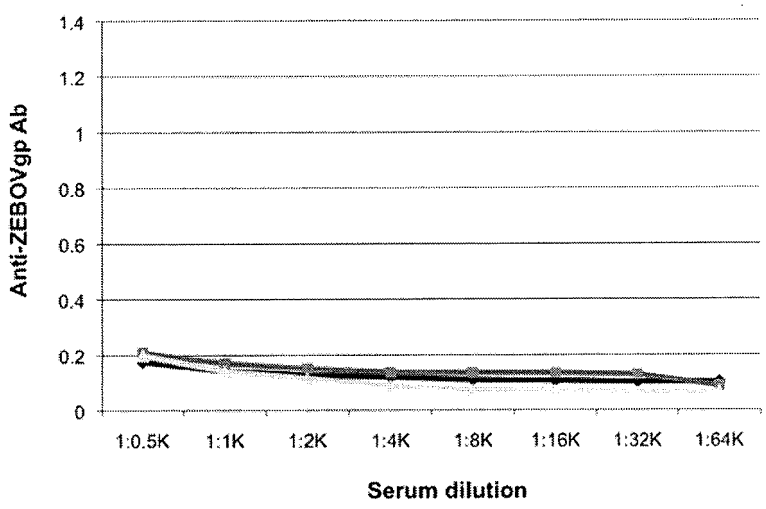

1.4
1.2
1
0.8
0.6
0.4
0.2
0
Anti-ZEBOVgp Ab
1:0.5K
1:1K
1:2K
1:4K
1:8K
1:16K
1:32K
1:64K
Serum dilution

FIGURE 12

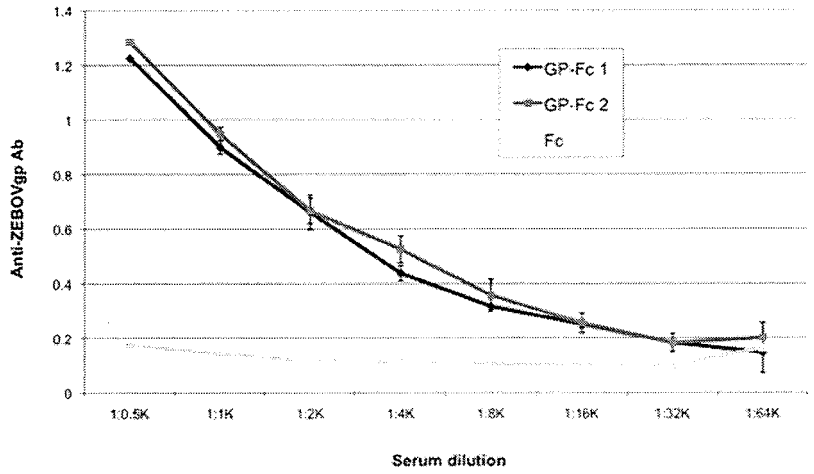
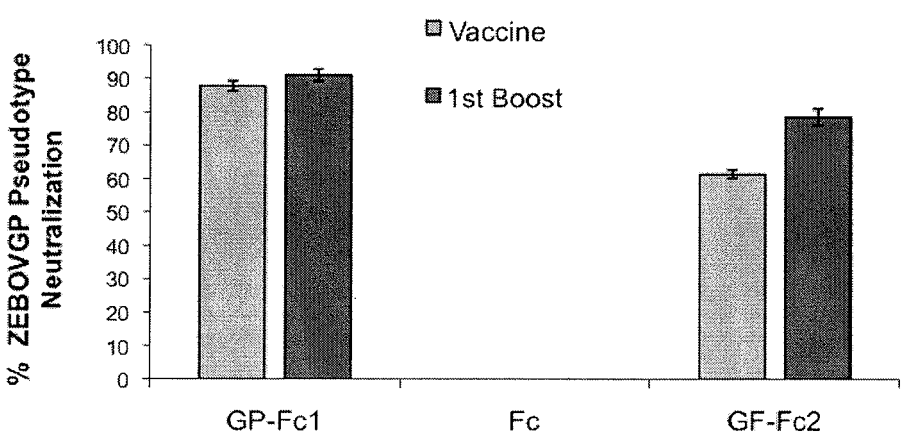

1.4
1.2
1
0.8
0.6
0.4
0.2
0
Anti-ZEBOVgp Ab
GP-Fc 1
GP-Fc 2
Fc
1:0.5K
1:1K
1:2K
1:4K
1:8K
1:16K
1:32K
1:64K
Serum dilution

FIGURE 13


% ZEBOVGP Pseudotype Neutralization
100
90
80
70
60
50
40
30
20
10
0
Vaccine
1st Boost
GP-Fc1
Fc
GF-Fc2

REFERENCES CITED IN THE DESCRIPTION

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